OFFSHORE OPERATORS COMMITTEE

September 29, 2009

Recipients:

Cooling Water Intake Structure Source Water Biological Baseline Characterization Study

The attached report, prepared by LGL Ecological Research Associates, Inc., presents the results of the industry-wide Cooling Water Intake Structure Source Water Biological Baseline Characterization Study that was organized by the Offshore Operators Committee to assist participating companies in meeting their requirements related to new facilities with regulated cooling water intakes under Part I.B.12.a of NPDES General Permit GMG 290000 issued 10/1/07. This study was conducted according to a plan approved by EPA Region 6 on June 27, 2008 for meeting baseline study requirements under the industry-wide study option provided by Permit GMG29000.

The study provides a comprehensive review of fishery data for Gulf of Mexico species to support the evaluation of the impacts of regulated cooling water intakes. The data review summarizes species occurrence, life history, and significance to commercial, recreational, and forage base fisheries. The fishery data have been organized into a Geographical Information System format that provides the basis for an experienced fisheries analyst to evaluate the impacts of future cooling water intakes anywhere in the Gulf of Mexico. A development scenario, based on Minerals Management Service and industry data on likely future activity, provided an estimate of the location and magnitude of new cooling water use. The fishery data and development scenario were used to model the impacts of intakes on species found in the deepwater areas of the Central and Western Gulf of Mexico, where new cooling water intakes are expected to be installed. Because of the low densities of fish eggs and larvae in these areas, and the relatively small volumes of water used, the impacts predicted for the anticipated development scenario were predicted to be very small.

The results of this study were reviewed with EPA staff on August 24, 2009. The attached report contains significant new information and analyses prepared to address comments stemming from that review. The report Addendum presents a ranking of species by larval density as a means of gauging susceptibility to entrainment independently of species significance. Total egg and larval densities are summarized by geographic region and month to provide a basis for evaluating the seasonal dependence of the presence of fish eggs and larvae. A control volume approach is presented to provide a means of estimating impacts on species for which detailed life history data are not available. The material in the Addendum reinforces and confirms the primary conclusion of the main body of the report: that anticipated new cooling water use under the anticipated development scenario will have a very small impact on marine life.

Please direct any questions about this report to me at joe.p.smith@exxonmobil.com.

Very truly yours,

Joseph P. Smith

Joseph P. Smith
Chair, Cooling Water Intake Structure
Steering Group

GULF OF MEXICO COOLING WATER INTAKE STRUCTURE: SOURCE WATER BIOLOGICAL BASELINE CHARACTERIZATION STUDY

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for

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EXECUTIVE SUMMARY

Under the Clean Water Act Section 316(b) Phase III regulations, the National Pollutant Discharge Elimination System permit for the Western and Central Portions of the Gulf of Mexico (GOM) requires that operators of new facilities with Cooling Water Intake Structures (CWIS) that take in more than 2 million gallons per day (MGD) of seawater with more than 25% of that used for cooling water to (1) undertake source water biological baseline surveys, (2) conduct frequent visual or remote inspections of CWIS, and, (3) for some facilities, conduct entrainment monitoring studies. The permit provides operators with the choice of either doing individual site-specific studies to meet these requirements or to participate in a joint industry study, conducted under a plan to be approved by the Environmental Protection Agency (EPA). "CWIS" will be used throughout this document to refer to facilities that would be included in the permit due to intake volume and purpose criteria.

The Offshore Operators Committee endorsed the joint study approach and charged the Offshore Operators Committee-Environmental Sciences Subcommittee (OOC-ESS) with the task of setting up and managing the program for the affected operators. A phased approach was chosen with the initial task consisting of a desk-top study that involved the collection and synthesis of biological data about the GOM relevant to the permit requirements. The OOC-ESS required that the review and analyses not only be sufficient for meeting permit requirements, but that they also be sufficient for placing entrainment and impingement loss in an appropriate ecological perspective.

The objectives of the initial desk-top study phase were:

1. To provide an ecologically sound basis for the identification of regionally-specific key species for analysis of entrainment and impingement impacts;
2. To provide a synthesis of biological data available for making the impact assessment of offshore cooling water intakes in the GOM, and conduct the assessments where possible; and
3. To identify any additional data that may be required to meet the information needs outlined in the permit.

LGL Ecological Research Associates, Inc. (LGL) was awarded a contract to conduct the *Gulf of Mexico Cooling Water Intake Structure Study* by the OOC-ESS. This report contains the results of that desk-top study. The ultimate goal was to provide CWIS entrainment assessments for critical species in the GOM based upon predicted seawater usage in the GOM as determined by OCC-EES development scenarios.

The issue of seawater intakes and their effects on the biological resources of the GOM has gained prominence in recent years in conjunction with liquefied natural gas (LNG) terminals proposed for construction in several areas of the central and western Gulf. The primary issue associated with LNG intakes has been their potential impacts on fishery stocks resulting from the mortality of entrained eggs and larvae. Environmental assessments of all proposed LNG facilities in federal waters of the GOM fall under the jurisdiction of the U.S. Coast Guard (USCG) and the Maritime Administration (MARAD). The USCG and MARAD have established strict analytical protocols for assessing the impact of seawater intake on key fish species of the region. They include 1) the use of existing databases to estimate larval and egg densities in the vicinity of any proposed facility, 2) the use of forward-projecting Equivalent Adult Models (EAMs) to evaluate the expected levels of impacts from entrainment, and 3) the use of specific life-history parameters for assessing the individual fish species in question. For the most part, the assessment provided in this report adheres to the USCG/MARAD protocols. However, as LNG assessments have progressed over the years, modifications to the USCG/MARAD approach have been proposed. These alternate approaches are addressed where relevant in this report.

The initial task of the CWIS assessment was to compile a comprehensive list of marine and coastal fish and invertebrate species potentially subject to entrainment impacts in the northern GOM. Based upon EPA (2007), the list was to focus on those species that are important to recreational/commercial fisheries or are considered ecologically important to the Gulf ecosystem (e.g., forage fish). In addition, environmental profiles and assessments are also provided for those species in the Gulf listed as Threatened, Endangered or Protected by NMFS. Consistent with baseline study requirements, LGL conducted an exhaustive search of the scientific literature and compiled all relevant data that has been published for marine species living in the Gulf of Mexico.

LGL conducted a data search of the above files based on annual landings per year for the years 2000-2007. The time frame chosen was somewhat arbitrary but was intended to incorporate some historical perspective to the commercial and recreational fisheries in the GOM while at the same time focusing on the most recent years of the fisheries. Target species for CWIS assessments were based upon the top down prioritization of those taxa that are the principal components of the GOM commercial and recreational fisheries. The commercial fishery listing was prioritized in terms of dollar value of annual landings. The recreational listing was prioritized in terms of net weight of annual landings.

In order to implement the USCG/MARAD assessment protocols, the seawater intake rate and several pieces of fishery-related information must be known or calculated: egg and larval densities for the target species, entrainment loss, the instantaneous natural daily mortality rate of the species, and stage durations. In effect, assessments attempt to determine, by species, the number of eggs and larvae lost to CWIS entrainment and how those losses eventually affect the population. Life-history data on egg and larval stages are necessary to distinguish that proportion of those eggs and larvae lost to entrainment that would have died from natural causes anyway. Entrained eggs and larvae that would have died from natural causes are not counted as entrainment losses from CWIS activity. To determine CWIS entrainment rate, the densities of fish eggs and larvae must be known for the specific study region. In the early stages of the GOM LNG assessment process, a review of available literature and discussions with NOAA Fisheries identified the Southeast Area Monitoring and Assessment Program (SEAMAP) database as the best representation of existing ichthyoplankton (fish eggs and larvae) conditions in offshore waters of the GOM. Ichthyoplankton sampling has been conducted in the GOM as part of SEAMAP from 1982 to 2004 (most recent update of the SEAMAP database; the project is ongoing) and some 7,700 samples (plankton tows) have been collected. These data were the principal source for determining the densities of eggs and larvae in specific areas of the Gulf. These densities are then incorporated with seawater withdrawal estimates projected for future CWIS facilities planned for the Gulf to determine the annual loss of eggs and larvae by species.

For CWIS assessment purposes, the GOM was subdivided into 15 zones (Figure E1). The two major north-south divisions correspond approximately to the boundaries between the Western (W), Central (C), and Eastern (E) Planning Areas established by the Minerals Management Service (MMS) for offshore oil and gas leasing.

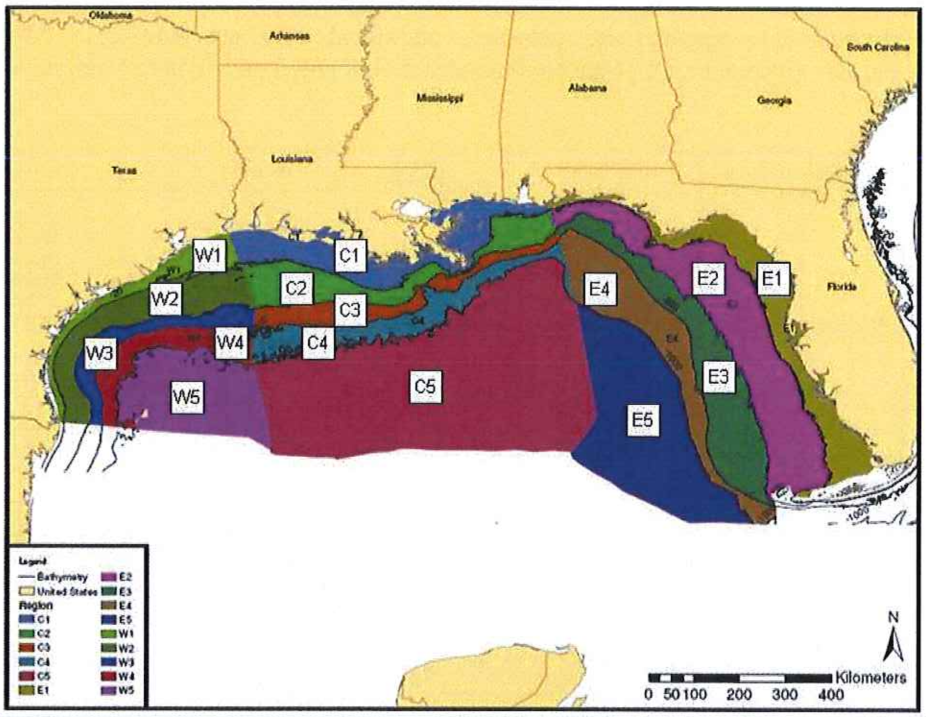

Figure E1. Zones for fishery data and water-use assessment.

Each of the three planning areas is further subdivided into five depth zones. The depth ranges of the zones 1 through 5 correspond, respectively, to 0-20 m, 20-60 m, 60-200 m, and 200-1000 m, and >1000 m. The three shallowest zones represent waters of the continental shelf. The depth boundaries for these zones are presently used in shrimp trawl bycatch assessments based upon their biological homogeneity. Depth zone 4 covers the continental slope and depth zone 5 deep abyssal waters out to the limit of the EEZ.

The fishery data zones provide a framework for organizing available fishery data (e.g. SEAMAP measurements of larval and egg densities, observations on the occurrence of adult fish of various species) so that the data can be used in a consistent way for the assessment of entrainment impacts due to the operation of CWIS that may be installed in any zone.

Developing an appropriate ecological perspective on the significance of entrainment losses requires the analysis of a water use scenario based on realistic intake volume and geographic distribution assumptions. The OOC-EES provided a development scenario report that estimated future cooling water intake volumes for each of the 15 zones. The development scenario addressed new seawater use over the 2009-2011 time frame to correspond with the range of known delivery dates for new drilling rigs. The number of

Table E1. Base case seawater use scenario – additional water use 2009-2011. MGD = million gallons per day (Appendix C). Shaded areas denote the only zones where future CWIS activity is projected.

	Production Facilities		Drill Ships		Semi submersibles		Jackups		Total		
Fishery Zone	Number	Total Water Usage (MGD)	Number	Total Water Usage (MGD)	Number	Total Water Usage (MGD)	Number	Total Water Usage (MGD)	Daily Water Usage (MGD)	Daily Water Usage Million Cubic Meters	Annual Water Usage Million Cubic Meters
E1	0	0	0	0	0	0	0	0	0	0	0
E2	0	0	0	0	0	0	0	0	0	0	0
E3	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0	0	0
C3	0	0	0	0	0	0	0	0	0	0	0
C4	2	7	0	0	1	8	0	0	15	0.05678	20.73
C5	5	55	5	180	1	8	0	0	243	0.91986	335.75
W1	0	0	0	0	0	0	0	0	0	0	0
W2	0	0	0	0	0	0	0	0	0	0	0
W3	0	0	0	0	0	0	0	0	0	0	0
W4	1	4	0	0	0	0	0	0	4	0.01514	5.53
W5	1	11	1	36	0	0	0	0	47	0.17791	64.94
Total	9	77	6	216	2	16	0	0	309	1.16969	426.94

New production platforms installed during that time frame was estimated from MMS predictions. New CWIS were assigned to zones based on known water depth specifications of various facility types and the percentage of each zone currently under lease. The relevant information on future CWIS seawater usage is presented in Table E1. Seawater volumes are converted from gallons to cubic meters. There are no future CWIS facilities planned for the Eastern Planning Area (Zones E1-E5), the three shallow water areas of the Central Planning Area (Zones C1-C3), and the three shallow water areas of the Western Planning Area (Zones W1-W3).

In terms of seawater usage, minimum development is projected for Zone W4, which consists of a single production facility at an annual usage rate of 5.53 million m^3. Heaviest development is projected for Zone C5 and includes five production facilities, five drill ships, and one semi-submersible for a cumulative seawater withdrawal rate of 335.75 million m^3 per year. Two production facilities and one semi-submersible are projected for Zone C4 (20.73 million m^3 per year), and one facility and one semi-submersible are projected for Zone W5 (64.94 million m^3 per year). Total new CWIS usage for the entire GOM by year-end 2011 is projected at 426.94 million m^3 per year. To provide a perspective on this amount of water use, this annual volume is about one-half the median amount used by a single coastal power plant (EPA 2002).

Findings

Currently in the GOM, there is only one species of fish or shellfish listed as Endangered (smalltooth sawfish), one species listed as Threatened (Gulf sturgeon), and 14 species listed as Species of Concern. Species of Concern are those species about which NMFS has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the Endangered Species Act. Five Species of Concern have largely freshwater distributions and are limited to low salinity coastal habitats. These species are not relevant to offshore development issues. Of the nine remaining listed species, six are irrelevant to CWIS entrainment issues because of their reproductive strategies—five (including the only species listed as Endangered) do not produce planktonic eggs and larvae, and the Gulf sturgeon (the only species listed as Threatened) spawns upriver in freshwater. The distribution of the seventh species is limited to the coastal waters of Florida and the Florida Keys and given the projected absence of CWIS development in the eastern GOM, it is unlikely that this species will be at risk to entrainment loss.

The only two listed species potentially to be impacted by CWIS entrainment are the speckled hind and Warsaw grouper. Their listing as Species of Concern means that although NMFS believes that the species may be at risk in the GOM, there is insufficient data on the stock structure, population size, and life history for the agency to make a definitive decision on risk analysis and the proper conservation steps. Our literature review similarly found that there is insufficient scientific information on the life-histories of these two species with which to make a CWIS assessment.

The taxon considered for CWIS assessment are listed in Table E2. Of the top 11 species (ordered by dollar value of annual landings) taken in GOM commercial fisheries, the top nine species have shallow water distributions in zones where there is no projected CWIS development (i.e.; Zone E1-E3, C1-C3, W1-W3). Environmental assessments are provided for the two remaining species—red snapper and yellowfin tuna. Using a fecundity-hindcasting model, the number of entrained eggs and larvae, by region, of these two species was converted into the number of equivalent eggs. That is, using life-history data, the number of eggs that would originally have had to have been produced to equal the total annual entrainment loss of all eggs and larvae. This reproductive loss is then converted into the number of spawning females required to produce those numbers of eggs on an annual basis. Based upon proposed CWIS future seawater withdrawal rates and using the fecundity hindcasting model, annual losses throughout the entire Gulf are estimated to be equivalent to < 1 female red snapper and 29 female yellowfin tuna. The 15 species of sharks fished commercially in the GOM (collectively ranked 17th) have reproductive strategies that render them immune to egg and larvae entrainment issues. There was insufficient life-history data to assess impacts to more minor species.

Table E2. Taxon considered for CWIS assessment.

Species	Rank	Fishery or Significance	Water Depth Range of Habitat	Spawning Behavior, Other Comments	Life History Available for CWIS Assessment	Present in CWIS Development Scenario Areas
Brown Shrimp (*Farfantepenaeus aztecus*)	1	Commercial	< 110m, mostly 30-55m	Sept and May at 27 m, Oct-Dec, Mar-May at 46 m	Yes	No
White Shrimp (*Litopenaeus setiferus*)	2	Commercial	< 40 m, mainly < 30 m	Mar- Oct, peak Jun-Jul, waters > 8 m	Yes	No
American Oyster (*Crassostrea virginica*)	3	Commercial	< 7.5 m	When waters > 20 C	No	No
Gulf Menhaden (*Brevoortia patronus*)	4	Commercial	< 120 m	Waters 2 - 128 m, but mainly <18 m, Oct-Mar	Yes	No
Blue Crab (*Callinectes sapidus*)	5	Commercial	< 90 m, mainly < 35 m	Spawns < 20 m depth, Mar-Aug. Eggs are not released and are not entrainable	Yes	No
Pink Shrimp (*Farfantepenaeus duorarum*)	6	Commercial	< 65 m , rarely to 110 m	Spawns 4-48 m, mainly Apr-Jul	No	No
Gulf and Florida Stone Crabs (*Menippe spp.*)	7	Commercial	< 61 m	Spawning year round, peak Dec-Feb. Eggs not released and are not entrainable	No	No
Spiny Lobster (*Panulirus argus*)	8	Commercial	< 80 m	Offshore Florida mainly. Mar-Jul. Not known to spawn in shallow waters	No	No
Red Grouper (*Epinephelus morio*)	9	Commercial	< 200 m, mainly 30 -120 m, occasionally to 500 m	Spawns 25 - 90 m, Jan-May	No	No
Red Snapper (*Lutjanus campechanus*)	10	Commercial	Larger adults 55-92 m, rarer inshore and offshore of this range, high value habitat 18-64 m	Spawns offshore, Jun Aug	Yes	Yes
Yellowfin Tuna (*Thunnus albacares*)	11	Commercial	60 - 1000+ m central and western gulf, generally found in top 100 m of water	Spawns May-Dec	Yes	Yes
Sharks and Rays (15 species)	17	Commercial	Gulf wide	No planktonic eggs or larvae, not relevant to entrainment assessment	No	NA
Red Drum (*Sciaenops ocellatus*)	1	Recreational	< 40 m	Nearshore, Aug-Oct	Yes	No
Spotted Seatrout (*Cynoscion nebulosus*)	2	Recreational	<20 m	Spawns <3-4 m depth	No	No
Sheepshead (*Archosargus probatocephalus*)	3	Recreational	Estuaries	Spawns 15 - 25 m (limited data), Jan-May	No	No
Red Snapper (*Lutjanus campechanus*)	4	Recreational	See data for commercial fishery	See data for commercial fishery	Yes	Yes
Gag Grouper (*Mycteroperca microlepis*)	5	Recreational	< 150 m, demersal	Spawns Jan-May	No	No
King Mackerel (Scomberomorus cavalla)	6	Recreational	< 200 m	Spawns May-Sep, peak late May - early Aug	No	No
Spanish Mackerel (Scomberomorus maculatus)	7	Recreational	< 100 m	Spawns Apr-Sep	No	No
Black Drum (*Pogonias cromis*)	8	Recreational	< 37 m	Spawns < 20 m	No	No
Dolphinfish (*Coryphaena hippurus*)	9	Recreational	20 - 1000 m+	In warm waters spawn all year, peak in spring and fall	No	Yes
Other Fishes	10	Recreational	NMFS category - NA	NA	NA	NA
Anchovies (Engraulidae)	1	Forage Fish	bays inshore coastal to brackish	Spawn year round	Yes	Yes
Smalltooth Sawfish (Pristis pectinata)	N/A	Endangered	Currently found in peninsular Florida waters, relatively common only near the southern tip of the state.	Ovoviparous, young 60 cm at birth , not subject to entrainment	No	No
Gulf Sturgeon (*Acipenser oxyrinchus desotoi*)	N/A	Threatened	Major river systems	Spawn in freshwater	No	No
Dusky shark (*Carcharhinus obscurus*)	N/A	Species of Concern	Rare in the Northern GOM except at Flower Garden Banks.	Viviparous. Young are not subject to entrainment	No	No
Largetooth sawfish	N/A	Species of	Nearshore waters, including the	Ovoviparous, young 60 cm at birth	No	No

Species	Rank	Fishery or Significance	Water Depth Range of Habitat	Spawning Behavior, Other Comments	Life History Available for CWIS Assessment	Present in CWIS Development Scenario Areas
(*Pristis pristis*)		Concern	GOM,	, not subject to entrainment		
Night shark (*Carcharinus signatus*)	N/A	Species of Concern	Occurs in GOM near shelf edges of 100 – 600 m depth	Viviparous. Young are not subject to entrainment	No	Yes
Sand tiger shark (*Carcharias taurus*)	N/A	Species of Concern	Shoreline to 191 m	Young born fully developed, not subject to entrainment	No	Yes
Speckled hind (*Epinephelus drummondhayi*)	N/A	Species of Concern	Entire GOM, rocky bottoms 25-400m	Spawns July-September	No	Yes
Warsaw grouper (*Epinephelus nigritus*)	N/A	Species of Concern	Continental shelf break, 55-525 meters.	Spawns August-September	No	Yes
Dusky shark (Carcharhinus obscuris)	N/A	Species of concern	Occurs in GOM but rare in Northern waters except Flower Gardens Banks	Viviparous. Young are not subject to entrainment	No	No
Nassau grouper (*Epinephelus striatus*)		Species of concern	Shoreline to 90 m, including Florida Keys to central Louisiana	Spawns December – February.	No	No

Of the top 10 species (ranked in order of weight landed) taken recreationally in the GOM, seven have shallow water distributions in zones where there is no projected CWIS development. The 4th ranked species is the red snapper described above. The taxa ranked 10th by NMFS is classified as "Other Fish", for which no assessment was possible. For dolphinfish—the remaining species—there was insufficient life-history information in the scientific literature with which to conduct CWIS assessments.

Entrainment losses of all five species of Engraulidae (anchovies) were estimated en masse. Anchovies are considered a principal forage fish in the Gulf. Annual entrainment losses, expressed as a fraction of the standing biomass of forage fish in the GOM, were estimated to be between 5.893×10^{-7} and 2.806×10^{-6} .

In general, the greatest biological concentration of key marine species, including their spawning habitat, is restricted to the waters of the continental shelf (< 200 m in depth) of the GOM. There is no projected CWIS development for this area. All CWIS development is projected for deeper areas of the continental shelf (200-1,000 m water depths) and the abyssal plain (>1,000 m). Of the few species that reproductively occupy these deeper waters and for which there was sufficient life-history data available, entrainment losses are estimated to be nominal for several reasons. For taxa like red snapper and anchovies, waters of the continental slope represent the periphery or outer limits of their spawning habitat. Egg and larval densities are much lower than for shallower areas. For pelagic species like yellowfin tuna, reproductive output is dispersed over wide oceanic areas resulting in egg and larval densities that are quite low at any specific site. Lastly, total new CWIS usage to be added to the entire GOM by year-end 2011 is projected at 426.94 million m^3 per year. By comparison, the projected seawater usage rate for seven proposed LNG terminals in the northern Gulf was 1,464 million m^3 per year (Gallaway et al. 2007). Further, these terminals were to be located in areas of the continental shelf with significantly higher egg and larval densities than are expected in the areas predicted for new CWIS installations. Assessments by Gallaway et al. (2007) found that even under these conditions, entrainment loss for two of the most important commercial and recreational species in the GOM—red snapper and red drum— would have minor adverse impacts on the two stocks, suggesting that facilities using a smaller volume of water and located in deeper waters, where egg and larval densities are lower, would have even smaller impacts on these species. Overall, the new seawater use scenario examined in this study would have minimal impacts on the species assessed.

Scope of CWIS Baseline Study

A significant effort was made to comprehensively survey the available fishery information for all regions of the Gulf of Mexico. Much background data are presented in the body of the report for certain species and regional larval and egg density estimates were compiled. For some key species, no development is planned to occur in their spawning grounds and thus no assessment of larval and egg entrainment loss is needed. Nevertheless, full biological backgrounds are presented, and egg and larval density information obtained, for each species for which that information exists. This discussion is intended to provide a means of accessing the full extent of information in the scientific literature on the species of interest. This information will be of use in the event that new areas of the Gulf of Mexico become available for future development. Using the framework developed in this report, density information from the most recent SEAMAP datasets could be updated and used to develop an entrainment impact assessment in a consistent way for a facility located anywhere in the GOM.

The following Table E3 provides a summation of the CWIS desk-top study relative to the eight requirements in the EPA (2007) description of Source Water Baseline Biological Survey (SWBBS).

Table E3. Summation of CWIS desk-top study relative to the eight requirements in the EPA (2007) description of SWBBS.

Source Water Biological Baseline Study Requirement	Comments
A list of the data required by this section that are not available and efforts made to identify sources of the data;	The project team consisted of experts on Gulf of Mexico fishery studies and involved a comprehensive review of the literature. Life history data are not specifically required by this section but they are needed for analysis of the significance of entrainment losses. Life history data for one of the relevant deepwater species (tuna) were not available prior to this study. To address this gap, the project team developed a set of life history parameters for yellowfin tuna based on a review of the scientific literature. However, there was insufficient data in the literature to develop life history parameters for every species considered in this study. Vertically resolved ichthyoplankton density data, although not strictly required by this section, would be useful for entrainment assessment but are absent from the most important Gulf of Mexico ichthyoplankton databases.
A list of species (or relevant taxa) for all life stages and their relative abundance in the vicinity of the cooling water intake structure;	The scientific literature and fishery management statistics were reviewed to develop a prioritized list of the most important Gulf of Mexico species. The list of species includes those that have commercial, recreational, and forage fish significance. The geographic distribution of species was imported into a Geographic Information System that can be queried to list the species relevant to facilities in any desired zone of the GOM. Egg and larval densities are presented for assessed species in zones where new CWIS are likely to be installed. Based on the geographic framework presented here, an experienced fishery analyst could query the most recent version of fishery databases such as SEAMAP to develop egg and larval density data for any zone in the GOM.
Identification of the species and life stages that would be most susceptible to impingement and entrainment. Species evaluated should include the forage base as well as those most important in terms of significance to commercial and recreational fisheries;	Of the 21 species reviewed, 13 do not have eggs or larvae present in areas of the GOM where regulated CWIS are expected to be installed. These species are not considered to be susceptible to entrainment under the current development scenario. Other species have some susceptibility to entrainment.
Identification and evaluation of the primary period of reproduction, larval recruitment, and period of peak abundance for relevant taxa;	Out of 21 species reviewed, 2 did not produce pelagic eggs or larvae and are thus not relevant for entrainment assessment. Of the remaining 19 species, some information was available on the seasonality of spawning behavior that defines the primary period of reproduction.

Table E3. Continued.

Source Water Biological Baseline Study Requirement	Comments
Identification of all threatened, endangered, and other protected species that might be susceptible to impingement and entrainment at your cooling water intake structures;	A section entitled "Threatened Endangered and other protected species" presents data on these species.
If the information above is supplemented with data from field studies, the supplemental data must include a description of all methods and quality assurance procedures for sampling and data analysis including a description of the study area; taxonomic identification of sampled and evaluated biological assemblages (including all life stages of fish and shellfish); and sampling and data analysis methods. The sampling and/or data analysis methods you use must be appropriate for a quantitative survey and based on consideration of methods used in other biological studies performed within the same source water body. The study area should include, at a minimum, the area of influence of the cooling water intake structure;	The current study did not involve field data collection.
Alternatively, operators may comply with these requirements and the entrainment monitoring requirements in section B.12.d of this permit through participation in an EPA approved industry-wide study. That study may include a smaller, statistically representative number of facilities. Any industry wide baseline study which is conducted must be commenced within one year after the effective date of this permit and completed within two years after the effective date. Any industry-wide study conducted to meet the entrainment monitoring requirements in section B. 12 must be commenced within two years after the effective date of this permit or the installation of a new facility subject to the cooling water intake structure requirements of Part I.B. 12 whichever is later. The industry wide study must be completed three years after its commencement."	The current study is being carried out under the industry wide study option. The plan for the study has been approved by EPA
Additional analysis going beyond the requirements of this section	Of the four species identified as having some density of eggs or larvae in Zones where cooling water intake structures are expected to be installed, three species were subjected to a modeling analysis of the significance of the entrainment losses

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BO	Bongo Oblique
BOET	Bienville Offshore Energy Terminal
BH	Bongo Half Oblique
BS	Bongo Stratified
CI	95% Confidence Interval
CWIS	Cooling Water Intake Structures
EAM	Equivalent Adult Model
EEZ	Exclusive Economico Zone
EFH	Essential Fish Habitat
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FHM	Fecundity Hindcasting Models
FMP	Fisheries Management Plan
FSD	Fisheries Statistics Division
FWC	Fish and Wildlife Conservation
GIS	Geographic Information System
GMFMC	Gulf of Mexico Fisheries Management Council
GOM	Gulf of Mexico
GSMFC	Gulf States Marine Fisheries Commission
LDWF	Louisiana Department of Wildlife and Fisheries
LGL	LGL Ecological Research Associates, Inc.
LOOP	Louisiana Offshore Oil Port, Inc.
LNG	Liquefied Natural Gas
MARAD	Maritime Administration
MGD	Million gallons per day
MRFSS	Marine Recreational Fisheries Statistics Survey
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OOC-ESS	Offshore Operators Committee-Environmental Sciences Subcommittee
PSE	Proportional standard error
SEAMAP	Southeast Area Monitoring and Assessment Program
SWBBS	Source Water Baseline Biological Survey
TDPW	Texas Department of Parks and Wildlife
USCG	U.S. Coast Guard
ZSIOP	Sea Fisheries Institute, Plankton Sorting and Identification Center

INTRODUCTION

Under the Clean Water Act Section 316(b) Phase III regulations, the National Pollutant Discharge Elimination System (NPDES) permit for the Western and Central Portions of the Gulf of Mexico (EPA 2007) requires that operators of new facilities with Cooling Water Intake Structures (CWIS) that take in more than 2 million gallons per day (MGD) of seawater with more than 25% of that used for cooling water to (1) undertake source water biological baseline surveys, (2) conduct frequent visual or remote inspections of CWIS, and, (3) for some facilities, conduct entrainment monitoring studies. The permit provides operators with the choice of either doing individual site-specific studies to meet these requirements or, for requirements 1 and 3, to participate in a joint industry study, conducted under a plan to be approved by Environmental Protection Agency (EPA) Region 6, aimed at meeting the requirements. It is anticipated the EPA Region 4 will incorporate 316(b) Phase III similar to those in Region 6 in upcoming permits. The Gulf of Mexico (GOM) areas of interest therefore include waters regulated by both EPA Region 6 and EPA Region 4. The EPA (2007) permit requirements of the Source Water Baseline Biological Survey (SWBBS) are listed in Table 1.

The Offshore Operators Committee endorsed the joint study approach and charged the Offshore Operators Committee-Environmental Sciences Subcommittee (OOC-ESS) the task of setting up and managing the program for the affected operator selected to take advantage of Provision 8. A phased approach was chosen with the initial task consisting of a desk-top study that involved the collection and synthesis of biological data about the GOM relevant to the permit requirements. A later phase may occur, if necessary, to collect specific, additional data that might be required to address permit requirements. The OOC-ESS required that the review and analyses not only be sufficient for meeting permit requirements, but that they also be sufficient for placing entrainment and impingement loss in an appropriate ecological perspective.

The objectives of the initial desk-top study phase were:

1. To provide an ecologically sound basis for the identification of regionally specific key species for analysis of entrainment and impingement impacts;
2. To provide a synthesis of biological data available for making the impact assessment of offshore cooling water intakes in the GOM, and conduct the assessments where possible; and
3. To identify any additional data that may be required to meet the information needs outlined in the permit.

On 23 October 2008, LGL Ecological Research Associates, Inc. (LGL) was awarded a contract to conduct the *Gulf of Mexico Cooling Water Intake Structure Study* by the OOC-ESS. This report contains the results of that desk-top study. The ultimate goal was to provide CWIS entrainment assessments for critical species in the GOM based upon predicted seawater usage in the GOM as determined by OCC-EES development scenarios.

Table 1. EPA (2007) description of SWBBS requirements.

"Operators of new facilities must submit sufficient information to characterize the biological community of commercial, recreational, and forage base fish and shellfish in the vicinity of the intake structure and to characterize the effects of the cooling water intake structure's operation on aquatic life. This biological characterization must include any available existing information along with field studies to obtain localized data.

1. *A list of the data required by this section that are not available and efforts made to identify sources of the data;*

2. *A list of species (or relevant taxa) for all life stages and their relative abundance in the vicinity of the cooling water intake structure;*

3. *Identification of the species and life stages that would be most susceptible to impingement and entrainment. Species evaluated should include the forage base as well as those most important in terms of significance to commercial and recreational fisheries;*

4. *Identification and evaluation of the primary period of reproduction, larval recruitment, and period of peak abundance for relevant taxa;*

5. *Data representative of the seasonal and daily activities (e.g., feeding and water column migration) of biological organisms in the vicinity of the cooling water intake structure;*

6. *Identification of all threatened, endangered, and other protected species that might be susceptible to impingement and entrainment at your cooling water intake structures;*

7. *If the information above is supplemented with data from field studies, the supplemental data must include a description of all methods and quality assurance procedures for sampling and data analysis including a description of the study area; taxonomic identification of sampled and evaluated biological assemblages (including all life stages of fish and shellfish); and sampling and data analysis methods. The sampling and/or data analysis methods you use must be appropriate for a quantitative survey and based on consideration of methods used in other biological studies performed within the same source water body. The study area should include, at a minimum, the area of influence of the cooling water intake structure.*

8. *Alternatively, operators may comply with these requirements and the entrainment monitoring requirements in section B.12.d of this permit through participation in an EPA approved industry-wide study. That study may include a smaller, statistically representative number of facilities. Any industry wide baseline study which is conducted must be commenced within one year after the effective date of this permit and completed within two years after the effective date. Any industry-wide study conducted to meet the entrainment monitoring requirements in section B. 12 must be commenced within two years after the effective date of this permit or the installation of a new facility subject to the cooling water intake structure requirements of Part I.B. 12 whichever is later. The industry wide study must be completed three years after its commencement."*

BACKGROUND: CWIS ASSESSMENTS IN THE GULF OF MEXICO

Offshore facilities rely on the intake of seawater to support normal operations. Seawater uses include process cooling, vaporization of liquefied natural gas (LNG), vessel ballast, fire suppression, reservoir pressure maintenance, and desalination. Typical rates for cooling water use by various facility types are shown in Figure 1. Withdrawal of seawater can result in mortality of fish and shellfish eggs and larvae when they are entrained, .i.e., drawn into, facility intakes. Entrainment losses of eggs and larvae have been the focus of environmental impacts studies of seawater use by Gulf of Mexico facilities (USCG and MARAD 2004, 2005a, 2006a). This is an indication that the use of fine-mesh wire screens to cover larger intakes, and designs for low intake face velocities are considered effective in reducing entrainment and impingement (i.e., harm from being trapped by flow forces against an intake screen) losses of juvenile and adult organisms.

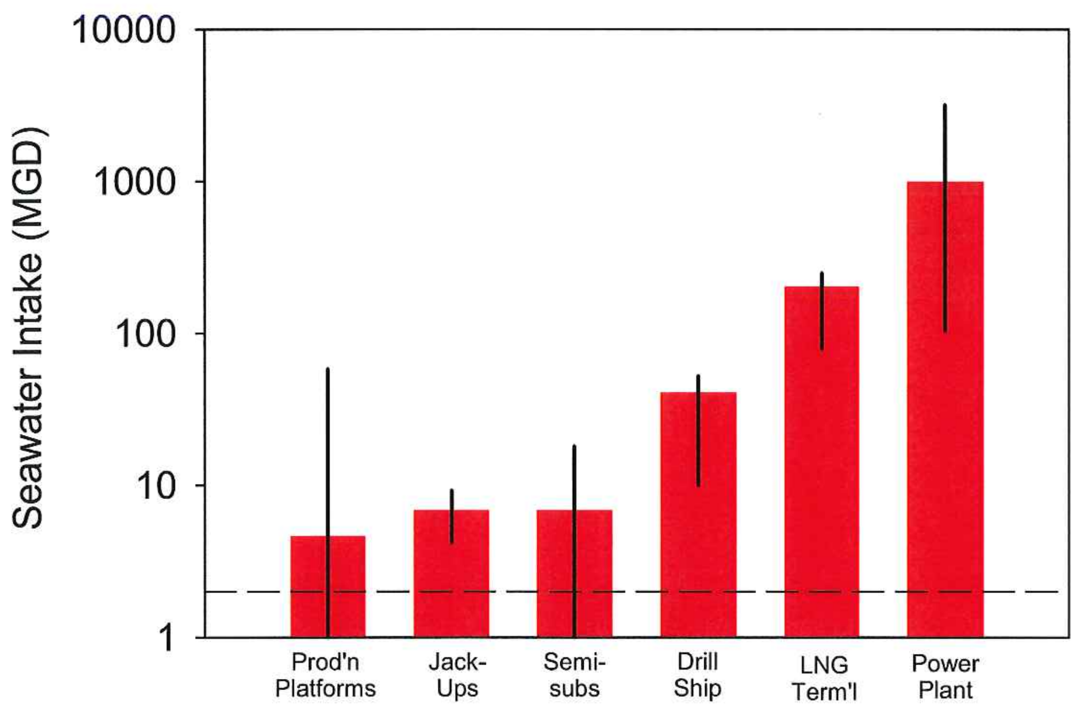


Figure 1. Median (columns) and ranges (bars) of total facility seawater intake rates (on a logarithmic scale) for offshore and coastal facilities. The dashed horizontal line indicates the threshold for entrainment baseline and monitoring studies for new offshore facilities in the U.S. Gulf of Mexico. Sources: Anonymous(Undated), California Public Utilities Commission (Undated), Duke Energy, LLC(2004), Rogers (2006), USCG (2002, 2003, 2004a, 2004b, 2004d, 2005, 2006), EPA(2002, 2004), Offshore Operators Committee (2009).

The issue of seawater intakes and their effects on the biological resources of the GOM has gained prominence in recent years in conjunction with LNG terminals proposed for construction in several areas of the central and western Gulf. The primary issue associated with LNG intakes has been their potential impacts on fishery stocks resulting from the mortality of entrained eggs and larvae (USCG and MARAD 2003, 2004, 2005a, 2005b, 2006a, 2006b; TORP 2006). Environmental assessments of all proposed LNG facilities in federal waters of the GOM fall under the jurisdiction of the U.S. Coast Guard (USCG) and the Maritime Administration (MARAD). The USCG and MARAD have established strict analytical protocols for assessing the impact of seawater intake on key fish species of the region (USCG and MARAD 2003, 2004, 2005a, 2005b, 2006a, 2006b; TORP 2006). They include 1) the use of existing databases to estimate larval and egg densities in the vicinity of any proposed facility, 2) the use of forward-projecting Equivalent Adult Models (EAMs) to evaluate the expected levels of impacts from entrainment, and 3) the use of specific life-history parameters for assessing the individual fish species in question. The standardized protocols were developed so that the same set of techniques could be used for each of the multiple facilities that were being proposed. EPRI (2004, 2005) and Gallaway et al. (2007) noted that the use of EAMs was not always appropriate and proposed that Fecundity Hindcasting Models (FHMs) be used, especially given that they would be used in conjunction with the existing stock assessment models to estimate the impacts of entrainment on stocks and yield.

Because these LNG assessments of seawater withdrawal are among the most recent, the USCG/MARAD protocols supplemented with the EPRI (2004, 2005) and Gallaway et al. (2007) approach, serves as the basis for our analysis.

THREATENED, ENDANGERED, AND OTHER PROTECTED SPECIES

Currently, the only species of fish or shellfish listed as Endangered in the GOM is the smalltooth sawfish (*Pristis pectinata*) (NMFS 2008d). The only species listed as Threatened is the Gulf sturgeon (Acipenser oxyrinchus desoti). There are currently no Candidate Species listed in the GOM (NMFS 2008d). Candidate Species are those petitioned species that are actively being considered for listing as endangered or threatened under the Endangered Species Act (ESA), as well as those species for which NMFS has initiated an ESA status review that it has announced in the Federal Register. Seven marine species are currently listed as Species of Concern: speckled hind (*E. drummondhayi*), Nassau grouper (*Epinephelus striatus)*, Warsaw grouper (*E. nigritus*), dusky shark (*Carcharhinus obscurus*), largetooth sawfish (*Pristis pristis*), sand tiger shark (Carcharias taurus), and the night shark (*Carcharhinus signatus*) (NMFS 2008d). Species of Concern are those species about which NMFS has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the ESA.

Five additional Species of Concern are the key silverside (*Menidia conchorum*), mangrove rivulus (*Rivulus marmoratus*), Alabama shad (*Alosa alabamae*), opossum pipefish (*Microphis brachyurus lineatus*), and saltmarsh topminnow (*Fundulus jenkinsi*). The key silverside and mangrove rivulus are restricted to waters of the Florida Keys and are not relevant to activities in the development area. The Alabama shad, opossum pipefish, and saltmarsh topminnow have largely freshwater distributions and are limited to low salinity coastal habitats. These species are not relevant to offshore development issues. These five species will not be discussed further.

Species Profiles

Species profiles provide a summary of biology and fishery information for a particular species. The profiles provide life history information, statewide landings, trends in catch rates, and results of recent stock assessments.

Smalltooth Sawfish

This species occurs worldwide in tropical to temperate seas. In the western Atlantic it occurs from northern Florida to central Brazil, including the GOM and the Caribbean (McEachran and Fechhelm 2005). The current range of this species has contracted to peninsular Florida, and smalltooth sawfish are relatively common only in the Everglades region at the southern tip of the state (NMFS 2008d). The smalltooth sawfish is limited to inshore habitats, including bays, estuaries, and freshwater with connections to the sea. Embryonic development is ovoviviparous—eggs develop within the maternal body and hatch within or immediately after extrusion from the parent (McEachran and Fechhelm 2005). Fish are 60 cm at birth.

Because of its reproductive strategy, egg and larval entrainment is not an issue with this species.

Gulf Sturgeon

Gulf sturgeon occur in most major river systems from the Mississippi River to the Suwannee River, Florida (Woodley and Crateau 1995). Although once abundant throughout the eastern GOM, population numbers have declined dramatically since the early 1900s (USFWS/GSMFC 1995). This decline has been attributed to blockage of spawning sites by dams, loss of suitable habitat, pollution, and overexploitation (Woodley and Crateau 1995). The UFWS and NMFS designated the Gulf sturgeon as a Threatened species, pursuant to the ESA of 1973, as amended. The listing became official on September 30, 1991 (USFWS/GSMFC 1995).

Gulf sturgeon spawn in freshwater and may travel hundreds of kilometers upriver. These eggs and larvae are not exposed to offshore CWIS in the GOM.

Speckled Hind

This species occurs in the western Atlantic from North Carolina and Bermuda to Quintana Roo, including the Florida Keys and the entire GOM (McEachran and Fechhelm 2005). Speckled hinds are deepwater grouper with adults inhabiting offshore rocky bottoms at depths from 25 to 400 m but are most common between 60 and 120 m (NMFS 2008d). Spawning takes place between July and September. Fecundity ranges up to 2 million eggs per female (McEachran and Fechhelm 2005). Little information has been compiled for this species—the stock structure is not characterized, population size is unknown, and much of the life history has not been thoroughly investigated (NMFS 2008d).

Nassau Grouper

This species occurs between the shoreline and 90 m in the western Atlantic from northern Florida and Bermuda to southern Brazil, including the Bahamas and the northeastern GOM from the Florida Keys to central Louisiana. Nassau grouper are rare in the northwestern GOM (Hoese and Moore 1998). Sadovy and Eklund (1999) consider the northeastern GOM limit of the Nassau grouper's range to be around Tampa Bay, Florida.

Adults are associated with coral reefs, and juveniles occur in seagrass beds. Spawning takes place from December through February near time of full moon along the outer reef edge. Assemblages of 3 to over 200,000 adults take part in group spawnings (McEachran and Fechhelm 2005). Spawning aggregation sites are characteristically small, highly circumscribed areas, measuring several hundred meters in diameter, with soft corals, sponges, stony coral outcrops, and sandy depressions (10 references cited in Sadovy and Eklund 1999). Eggs and larvae are pelagic. Currents in the vicinity of aggregation sites do not necessarily favor offshore transport (Sadovy and Eklund 1999), and Nassau grouper larvae are rarely reported from offshore waters (Leis 1987).

Given limited distribution of the Nassau grouper in the northern GOM, the tendency to live and spawn in shallow reef areas, and the apparent lack of offshore transport of eggs and larvae, it is unlikely that the eggs and larvae of this species will be subject to seawater entrainment in offshore waters of the Gulf.

Warsaw Grouper

Warsaw grouper are classified as deep-water groupers because they inhabit reefs on the continental shelf break in waters 55 to 525 m in depth (NMFS 2008d). Juveniles occasionally occur around jetties and on shallow reefs (McEachran and Fechhelm 2005). The species is slow growing and long-lived, reaching ages up to 41 years (McEachran and Fechhelm 2005). Although Warsaw grouper spawn from August through September in the GOM, very little else is known about their reproduction (NMFS 2008d). Eggs and larvae are presumed to be pelagic.

Largetooth Sawfish

The largetooth sawfish occurs in tropical to temperate waters of the western Atlantic from northern Florida, the GOM, the Caribbean, and Bermuda to central Brazil (McEachran and Fechhelm 2005). This species is found near shore, including bays, estuaries, and freshwater with connections to the sea. Embryonic development is ovoviviparous—eggs develop within the maternal body and hatch within or immediately after extrusion from the parent (McEachran and Fechhelm 2005). Fish are 60 cm at birth.

Because of its reproductive strategy, egg and larval seawater entrainment is not an issue with this species.

Dusky Shark

This species occurs in the western Atlantic from Florida, Bermuda, the GOM, the Bahamas, Yucatán, Venezuela, and southern Brazil (McEachran and Fechhelm 2005). It is rare in the northern GOM, except at the Flower Gardens Banks reef. Development is viviparous (live birth) with litters ranging from four to six young. Young are about 73 cm at birth.

Because of its reproductive strategy, egg and larval seawater entrainment is not an issue with this species.

Sand Tiger Shark

This species occurs in tropical to temperate seas from the shoreline out to 191 m (McEachran and Fechhelm 2005). In the western Atlantic it occurs from the Gulf of Maine to southern Brazil, including Bermuda, the GOM, and the Bahamas. Embryonic development is ovophagous with young feeding on less-developed embryos and eggs in the uterus. Only a single embryo fully develops in each uterus (McEachran and Fechhelm 2005).

Because of its reproductive strategy, egg and larval seawater entrainment is not an issue with this species.

Night Shark

This species occurs in the tropical to warm temperate Atlantic, generally near the edge of continental and insular shelves at depths of 100 to 600 m (McEachran and Fechhelm 2005). In the western Atlantic it occurs from Delaware to Florida, the GOM, the Bahamas, and Cuba, and off southern Brazil and Argentina. Development is viviparous (live birth) with litters ranging from 4 to 12 young. Young are about 73 cm at birth.

Because of its reproductive strategy, egg and larval seawater entrainment is not an issue with this species.

Summary

Of the nine species listed as either threatened, endangered or other, six are irrelevant to CWIS entrainment issues because of their reproductive strategies—five do not produce planktonic eggs and larvae, and the Gulf sturgeon spawns upriver in freshwater. Given that the distribution of Nassau grouper is limited to the coastal waters of Florida and the Florida Keys, coupled with the projected absence of CWIS development in the eastern GOM, it is unlikely that this species will be at risk to entrainment loss.

The only two species potentially to be impacted by CWIS entrainment are the speckled hind and Warsaw grouper. Their listing as Species of Concern means that although NMFS believes that the species may be at risk in the GOM, there is insufficient data on the stock structure, population size, and life history for the agency to make a definitive decision on risk analysis and the proper conservation steps. Our literature similarly found that there is insufficient scientific information on the life-histories of these two species with which to make a CWIS assessment.

TARGET SPECIES

The initial task of the CWIS assessment was to compile a comprehensive list of marine and coastal fish and invertebrate species potentially subject to entrainment impacts in the northern GOM. Based upon EPA (2007), the list was to focus on those species that are important to recreational/commercial fisheries or are considered ecologically important to the Gulf ecosystem (e.g., forage fish). Important species are also identified based on species lists compiled in Gulf of Mexico Fisheries Management Council (GMFMC 2004): *Generic Essential Fish Habitat Amendment to the following Fishery Management Plans of the Gulf of Mexico*. Threatened and Endangered species are discussed separately in the following section.

Data Sources

The principal datafiles used in compiling fisheries landings information for the GOM were those provided by the Fisheries Statistics Division ST1 (FSD) of the National Marine Fisheries Service (NMFS) and the Texas Department of Parks and Wildlife (TDPW). The FSD datafile provides commercial landings data for the entire GOM as described below. The FSD datafile provides recreational landings data for the GOM excluding the state of Texas. Compilation of the FSD recreational fisheries database for the GOM represents the combined efforts of both state and federal agencies as part of the Marine Recreational Fisheries Statistics Survey (MRFSS). The state of Texas has chosen not to participate in MRFSS but instead maintains its own recreational fishery survey database managed by the TDPW.

NOAA Commercial and Recreational Fisheries Data

The FSD has automated data programs that summarize commercial and recreational fisheries landings in the U.S. These programs can be accessed via the NMFS website at http://www.st.nmfs.noaa.gov/st1/ (NMFS 2008a). Annual and monthly commercial landing summaries are available by state or region.

Commercial Landings. The collection of U.S. commercial fisheries landings data is a joint state and federal responsibility. The cooperative State-Federal fishery data collection systems obtain landings data from state-mandated fishery or mollusk trip-tickets, landing weighout reports provided by seafood dealers, federal logbooks of fishery catch and effort, shipboard and portside interviews, and biological sampling of catches. State fishery agencies are usually the primary collectors of landings data, but in some states NMFS and state personnel cooperatively collect the data. Survey methodology differs by state, but NMFS makes supplemental surveys to ensure that the data from different states and years are comparable.

For the GOM, data include landings for the states of Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida from the Alabama/Florida border east then south to approximately the Florida Keys. Landings are reported in pounds of round (live) weight for all species or groups except univalve and bivalve mollusks, such as clams, mussels, oysters and scallops, which are reported as pounds of meat (excludes shell weight). The dollar value of landings are reported as nominal (current at the time of reporting) values.

NMFS points out the following caveat for their landings statistics:

> *"Federal statutes prohibit public disclosure of landings (or other information) that would allow identification of the data contributors and possibly put them at a competitive disadvantage. Most summarized landings are non-confidential, but whenever confidential landings occur they have been combined with other landings and usually reported as "finfishes, unc" (unclassified) or "shellfishes, unc." Total landings by state include confidential data and will be accurate, but landings reported by individual species may, in some instances, be misleading due to data confidentiality."*

LGL conducted a data search based on annual landings per year for the years 2000-2007. The time frame chosen was somewhat arbitrary but was intended to incorporate some historical perspective to the commercial fisheries in the GOM while at the same time focusing on the most recent years of the fishery. Within this report, all commercial landings data (weight and dollar value) are reported as the annual average across the years 2000-2007 unless otherwise noted.

Recreational Landings. The MRFSS was developed in 1979 by the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service to monitor the relative size and impact of saltwater recreational fisheries in the United States. The survey has two components that complement each other. The field intercept component collects catch and harvest data through direct interviews with anglers that are intercepted at the end of their fishing trip. In Florida, biologists from the Florida Fish and Wildlife Conservation Commission (FWC) interview more than 45,000 anglers in the intercept survey each year. The effort survey component uses household telephone surveys to collect information on the number of fishing trips made in the state, including numbers of anglers and how often they go fishing. Combined, the two components of the MRFSS are used to estimate total catch, harvest, and effort in the recreational fishery.

For the GOM, the NOAA recreational database includes landings for the states of Louisiana, Mississippi, Alabama and the west coast of Florida from the Alabama/Florida border east then south to approximately the Florida Keys. Landings data for this report combine results for all types of fishing (shore, private/rental boats, head boats, and charter boats) and all fishing areas (inland, state territorial sea, state waters, and Federal Exclusive Economic Zone [EEZ]). Data combine both Type A (harvest based on observed harvest) and Type B1 (harvest based on reported harvest) landings. Type B2 (released alive) landings are not included.

Certain modifications were made to the data obtained from the FSD datafile. Data listings for recreational fisheries can be queried in one of several methods. Harvest data queried as "Snapshot" provides data for both species and broader taxonomic designations. For example, harvest data for sea basses (family Serranidae) yields four listings: (1) black sea bass (*Centropristis striata*), (2) *Epinephelus* groupers, (3) *Mycteroperca* groupers, and

(4) other sea basses. Harvest data queried as "Time Series" provides data for a specific yet select group of species. The time series query provided harvest data for gag (*Mycteroperca microlepis*), which is a *Mycteroperca* grouper, and red grouper (*Epinephelus morio*), which is an *Epinephelus* grouper. Summary results for the queries are presented in Table 2.

Table 2. Average recreational harvest for Serranidae across the years 2000-2007. The PSE, or proportional standard error, expresses the standard error of an estimate as a percentage of the estimate and is a measure of precision (NMFS 2008a).

Query	Common Name	Scientific Name	Harvest (No.)	Proportional Standard Error
Snapshot	Sea Bass, Black	*Centropristis striata*	307,400	19.6
	Groupers, Epinephelid	*Epinephelus* sp.	151,837	9.5
	Groupers, Mycteropercid	*Mycteroperca* sp.	350,778	8.0
	Sea Bass, Other	Serranidae	245,832	17.1
Time Series	Grouper, Red	*Epinephelus morio*	147,851	9.7
	Grouper, Gag	*Mycteroperca microlepis*	308,711	8.8
Revised Snapshot	Sea Bass, Black	*Centropristis striata*	307,400	19.6
	Grouper, Red	*Epinephelus morio*	147,851	9.7
	Groupers, *Epinephelus*	*Epinephelus* sp.	3,986	
	Grouper, Gag	*Mycteroperca microlepis*	308,711	8.8
	Groupers, *Mycteroperca*	*Mycteroperca* sp.	42,067	
	Sea Bass, Other	Serranidae	245,832	17.1

For 2000-2007, an average total of 151,837 (PSE = 9.5) *Epinephelus* groupers were taken throughout the GOM as per the "Snapshot" query. Based upon the "Time Series" query, a total of 147,851 (PSE = 9.7) red grouper were harvested in 2007. Inquiries to the NOAA (pers. comm., Rob Andrews, FSD; 23 September 2008) confirmed that the 147,851 red grouper are imbedded in the 151,837 *Epinephelus* harvest. Subtracting the red grouper harvest from the *Epinephelus* harvest yields a revised *Epinephelus* harvest of 3,986 fish. Note that the revised *Epinephelus* harvest has no standard error estimate. Whereas the revision to annual numbers caught is merely a matter of subtraction, standard errors are not. Without access to the raw data, standard errors for the revised catch of 3,986 fish cannot be calculated. Similar revisions were made for *Mycteroperca* groupers. Of the 350,778 *Mycteroperca* groupers taken, 308,711 were red grouper. Subtraction yielded a net of 42,067 *Mycteroperca* groupers (again no standard error). The Snapshot species listing in Table 2 would thus be adjusted to the Revised Snapshot listing.

Throughout the NOAA FSD database, select species are at times imbedded in higher taxonomic designation (pers. comm., Rob Andrews, Fisheries Statistics Division; 23 September 2008). To provide the greatest taxonomic detail possible, LGL has, where applicable, listed landings down to the species level and revised the higher taxonomic designation accordingly. Higher taxonomic levels that have had imbedded species data removed are always listed without a proportional standard error.

TDPW Recreational Fisheries Data

The data file for the Texas recreational fishery survey was obtained courtesy of Mark Fisher, TDPW (25 September 2008).

The TDPW creel survey year runs from 15 May to 14 May of the following year. It is divided into two seasons: high-use, which lasts from 15 May – 20 November, and low-use, which covers the period 21 November – 14 May. Both data sets are merged to yield annual catch counts. Data are segregated into three regions: inshore waters, Texas Territorial Sea, and the EEZ. For our analysis, average annual catches were compiled across all areas combined for the eight consecutive creel survey years of 1999-2000 through 2006-2007. Although the TDPW creel survey year does not overlap with the NMFS calendar year survey, it was felt that annual averages over eight years were, for the most part, comparable, particularly given that we were looking for clearly dominant species in the GOM recreational fishery.

Results

Commercial and Recreational Fisheries

Table 3 lists the 183 taxa taken commercially throughout the northern GOM (U.S. waters) in terms of weight landed (pounds) and dollar value. Data are listed in decreasing order of dollar value of the fishery. There are several taxa not listed in Table 3 because their yield is so low as to be considered meaningless. Taxa with landings of estimated annual value below $75 were considered commercially insignificant and not included in the list. Taxa entirely limited to freshwater ecosystems are also not listed. Table 4 lists the recreational fishing landings for the GOM (ex Texas) and for Texas. Data represents annual averages for the period 2000-2007. Data are listed in decreasing order by pounds landed for the GOM (ex Texas).

NMFS (2008a) reports that in terms of numbers caught, herring (no species identified) is the largest recreational fishery in the GOM with over 32 million fish taken annually. Over 99% of this catch comes from western Florida. The herring landings data, however, are the result of an artifact of sampling rather than true recreational landings. In the recreational fishing surveys, baitfish can be confused with the target species (Dr. Dave MacDonald, Gulf States Marine Fisheries Commission [GFMSC], pers. comm., 15 December 2008). In the Gulf, herring represent the baitfish that fisherman are using and are not targeted recreational species. Thus, the herring landings listed in NMFS (2008a) should be ignored (Dr. Dave MacDonald, Gulf States Marine Fisheries Commission, pers. comm., 15 December 2008). Accordingly, this category has been removed from the Table 3 listing.

Table 3. Fish and invertebrate taxa taken commercially in the northern GOM (U.S. waters) in decreasing order of commercial dollar value. All values are annual averages for the period 2000-2007. Source: Fisheries Statistics Division ST1 (FSD) of the NMFS (NMFS 2008a).

Common Name	Scientific Name	Pounds	Dollar Value (US)	Percent Dollar Value (US)
Shrimp, Brown	*Farfantepenaeus aztecus*	127,426,610	203,525,795	28.4
Shrimp, White	*Litopenaeus setiferus*	101,305,075	177,981,856	24.8
Oyster, Eastern	*Crassostrea virginica*	23,681,186	58,168,167	8.1
Menhaden, Gulf	*Brevoortia patronus*	1,081,127,556	54,144,592	7.6
Crab, Blue	*Callinectes sapidus*	61,128,125	43,619,711	6.1
Shrimp, Pink	*Farfantepenaeus duorarum*	13,237,192	27,809,743	3.9
Crab, Florida Stone Claws	*Menippe mercenaria*	5,800,380	24,171,885	3.4
Lobster, Caribbean Spiny	*Panulirus argus*	3,932,025	20,156,482	2.8
Grouper, Red	*Epinephelus morio*	6,300,903	12,944,474	1.8
Snapper, Red	*Lutjanus campechanus*	4,394,552	10,945,823	1.5
Tuna, Yellowfin	*Thunnus albacares*	3,349,396	10,491,828	1.5
Shrimp, Dendrobranchiata	Shrimp Suborder	2,762,392	8,407,760	1.2
Mullet, Striped (Liza)	*Mugil cephalus*	12,401,802	8,358,186	1.2
Gag	*Mycteroperca microlepis*	2,510,539	6,441,548	0.9
Snapper, Vermilion	*Rhomboplites aurorubens*	1,957,037	3,902,361	0.5
Drum, Black	*Pogonias cromis*	5,095,562	3,575,429	0.5
Snapper, Yellowtail	*Ocyurus chrysurus*	1,258,740	2,717,862	0.4
Grouper, Yellowedge	*Epinephelus flavolimbatus*	1,017,550	2,658,727	0.4
Shrimp, Rock	*Sicyonia brevirostris*	1,681,983	2,249,763	0.3
Sharks		874,311	2,019,884	0.3
Shrimp, Seabob	*Xiphopenaeus kroyeri*	4,653,430	1,970,282	0.3
Swordfish	*Xiphias gladius*	814,694	1,822,322	0.3
Catfish, Blue	*Ictalurus furcatus*	3,433,441	1,614,270	0.2
Mackerel, King and Cero	*Scomberomorus cavalla/regalis*	1,317,458	1,466,095	0.2
Mackerel, King	*Scomberomorus cavalla*	985,712	1,211,584	0.2
Amberjack, Greater	*Seriola dumerili*	1,087,468	1,056,163	0.1
Grouper, Black	*Mycteroperca bonaci*	417,192	1,054,001	0.1
Shrimp, Royal Red	*Pleoticus robustus*	470,095	1,048,030	0.1
Pompano, Florida	*Trachinotus carolinus*	308,544	995,822	0.1
Ladyfish	*Elops saurus*	1,437,907	862,799	0.1
Scamp	*Mycteroperca phenax*	325,697	846,620	0.1
Flatfish	Pleuronectiformes	407,373	797,752	0.1
Finfishes, Unc General		2,098,136	794,144	0.1
Mackerel, Spanish	*Scomberomorus maculatus*	1,335,034	731,828	0.1
Tilefish	Malacanthidae	439,419	682,412	0.1
Sheepshead	*Archosargus probatocephalus*	2,037,239	671,438	0.1
Catfish, Channel	*Ictalurus punctatus*	1,315,173	662,955	0.1
Buffalofishes	*Ictiobus spp.*	3,370,904	581,891	0.1
Shrimp, Marine, Other		214,729	581,576	0.1
Snapper, Gray	*Lutjanus griseus*	312,223	578,521	0.1
Finfishes, Unc Bait/Animal Food		1,700,423	570,156	0.1
Grouper, Snowy	*Epinephelus niveatus*	243,299	547,017	0.1
Ballyhoo	*Hemiramphus brasiliensis*	657,657	504,102	0.1
Scads	Carangidae	721,776	484,118	0.1
Dolphinfish	*Coryphaena hippurus*	349,132	455,029	0.1
Croaker, Atlantic	*Micropogonias undulatus*	86,695	451,349	0.1
Snapper, Mutton	*Lutjanus analis*	215,000	403,587	0.1
Sardine Spanish	*Sardinella aurita*	1,589,857	378,855	0.1
Butterfish, Gulf	*Peprilus burti*	802,857	361,029	0.1
Tuna, Bluefin	*Thunnus thynnus*	76,600	345,746	0.0
Shrimp, Atlantic & Gulf, Roughneck	*Trachypenaeus similis*	568,143	331,652	0.0
Grouper, Warsaw	*Epinephelus nigritus*	164,097	316,489	0.0
Shark, Blacktip	*Carcharhinus limbatus*	1,201,625	313,022	0.0
Grunts	Haemulidae	435,912	309,195	0.0
Herring, Atlantic Thread	*Opisthonema oglinum*	1,950,158	277,850	0.0
Crab, Deepsea Golden	*Chaceon fenneri*	233,354	258,468	0.0
Shad, Gizzard	*Dorosoma cepedianum*	1,149,656	252,390	0.0
Cobia	*Rachycentron canadum*	115,774	241,807	0.0

Table 3 Continued

Common Name	Scientific Name	Pounds	Dollar Value (US)	Percent Dollar Value (US)
Mullets	*Mugil* spp.	300,736	235,563	0.0
Shark, Sandbar	*Carcharhinus plumbeus*	822,699	235,166	0.0
Jack, Crevalle	*Caranx hippos*	387,572	233,819	0.0
Scups or Porgies	Sparidae	243,998	231,214	0.0
Pinfish	*Lagodon rhomboides*	44,340	215,985	0.0
Finfishes, Unc For Food		674,433	197,774	0.0
Mojarras	Gerreidae	249,333	187,975	0.0
Snapper, Silk	*Lutjanus vivanus*	80,838	177,109	0.0
Hind, Speckled	*Epinephelus drummondhayi*	79,726	165,502	0.0
Seatrout, Spotted	*Cynoscion nebulosus*	82,966	160,853	0.0
Wahoo	*Acanthocybium solandri*	135,889	158,912	0.0
Herrings	Clupeidae	1,007,150	156,300	0.0
Tuna, Little Tunny	*Euthynnus alletteratus*	392,580	144,981	0.0
Tuna, Bigeye	*Thunnus obesus*	38,511	132,672	0.0
Leatherjackets	Carnagidae	103,665	127,437	0.0
Catfish, Flathead	*Pylodictis olivaris*	255,478	121,971	0.0
Mackerel, Chub	*Scomber colias*	204,110	121,699	0.0
Runner, Blue	*Caranx crysos*	253,723	120,967	0.0
Bowfin	*Amia calva*	137,670	113,640	0.0
Bonito, Atlantic	*Sarda sarda*	80,325	112,630	0.0
Tilefish, Blueline	*Caulolatilus microps*	122,561	109,760	0.0
Sea Bass, Black	*Centropristis striata*	161,843	109,325	0.0
Porgy, Red	*Pagrus pagrus*	96,938	103,239	0.0
Flounder, Southern	*Paralichthys lethostigma*	83,869	99,322	0.0
Snapper, Lane	*Lutjanus synagris*	52,884	90,369	0.0
Escolar	*Lepidocybium flavobrunneum*	121,980	87,031	0.0
Groupers	Serranidae	38,315	84,480	0.0
Mullet, white	*Mugil curema*	149,670	83,001	0.0
Drum, Freshwater	*Apoldinotus grunniens*	541,676	82,136	0.0
Pigfish	*Orthopristis chrysoptera*	28,247	80,737	0.0
Hogfish	*Lachnolaimus maximus*	36,141	79,411	0.0
Amberjack, Lesser	*Seriola fasciata*	66,655	73,224	0.0
King Whiting	*Menticirrhus americanus*	126,338	73,057	0.0
Triggerfish, Gray	*Balistes capriscus*	68,194	70,827	0.0
Seatrout, Sand	*Cynoscion arenarius*	105,370	67,330	0.0
Shark, Atlantic Sharpnose	*Rhizoprionodon terraenovae*	140,138	55,309	0.0
Tilefish, Goldface	*Caulolatilus chrysops*	36,846	52,706	0.0
Jack, Almaco	*Seriola rivoliana*	52,718	48,527	0.0
Lobster, Slipper	*Syllarides squammosus*	10,512	46,370	0.0
Snapper, Queen	*Etelis oculatus*	19,694	41,868	0.0
Shark, Finetooth	*Carcharhinus isodon*	77,303	41,690	0.0
Scad, Bigeye	*Selar crumenophthalmus*	247,372	40,873	0.0
Bluefish	*Pomatomus saltatrix*	126,246	39,503	0.0
Oilfish	*Ruvettus pretiosus*	44,373	36,005	0.0
Jacks	Carangidae	59,810	34,820	0.0
Drum, Red	*Sciaenops ocellatus*	24,317	34,414	0.0
Cutlassfish, Atlantic	*Trichiurus lepturus*	35,776	33,237	0.0
Suckers	Catostomidae	81,078	31,501	0.0
Jack, Bar	*Caranx ruber*	38,080	31,259	0.0
Barrelfish	*Hyperoglyphe perciformis*	14,912	29,069	0.0
Snapper, Black	*Apsilus dentatus*	14,888	25,052	0.0
Permit	*Trachinotus falcatus*	17,361	24,949	0.0
Snappers	Lutjanidae	13,304	24,053	0.0
Anchovies	*Engraulidae*	106,489	23,212	0.0
Shark, Great Hammerhead	*Sphyrna mokarran*	89,196	21,795	0.0
Wenchman	*Pristipomoides aquilonaris*	16,674	21,318	0.0
Tuna, Blackfin	*Thunnus atlanticus*	31,901	21,077	0.0
Shark, Shortfin Mako	*Isurus oxyrinchus*	23,747	20,444	0.0
Shark, Bull	*Carcharhinus leucas*	70,871	19,604	0.0
Brotula, Bearded	*Brotula barbata*	16,608	18,401	0.0
Spadefish, Atlantic	*Chaetodipterus faber*	36,118	15,995	0.0
Black Driftfish	*Hyperoglyphe bythites*	11,137	15,591	0.0
Margate	*Haemulon album*	22,334	13,481	0.0

Table 3 Continued

Common Name	Scientific Name	Pounds	Dollar Value (US)	Percent Dollar Value (US)
Grouper, Yellowfin	*Mycteroperca venenosa*	5,948	13,415	0.0
Scorpionfishes	*Scorpaeniformes*	11,904	13,033	0.0
Porgy, Knobbed	*Calamus nodosus*	19,803	13,020	0.0
Spot	*Leiostomus xanthurus*	32,853	12,550	0.0
Shark, Lemon	*Negaprion brevirostris*	44,990	12,211	0.0
Tilefishes	Malacanthidae	26,584	12,128	0.0
Rudderfish, Banded	*Seriola zonata*	12,880	11,028	0.0
Snapper, Blackfin	*Lutjanus buccanella*	4,987	10,551	0.0
Shark, Spinner	*Carcharhinus brevipinna*	30,884	10,359	0.0
Tuna, Albacore	*Thunnus alalunga*	15,321	10,022	0.0
Mackerel, (Scomber)	Scombridae	15,479	9,363	0.0
Barracudas	*Sphyraena* spp.	14,835	9,324	0.0
Hind, Red	*Epinephelus guttatus*	5,447	9,202	0.0
Amberjack	*Seriola* spp.	8,738	7,778	0.0
Shark, Blacknose	*Carcharhinus acronotus*	21,928	7,656	0.0
Grouper, Marbled	*Dermatolepis inermis*	3,009	5,953	0.0
Grouper, Misty	*Epinephelus mystacinus*	2,557	5,557	0.0
Hake, Atlantic, Red/White	*Urophycis chuss/tenuis*	5,178	5,313	0.0
Tunas	Scombridae	2,298	5,212	0.0
Porgy, Whitebone	*Calamus leucosteus*	4,815	4,953	0.0
Flyingfishes	Exocoetidae	33,991	4,829	0.0
Porgy, Jolthead	*Calamus bajonado*	5,251	4,340	0.0
Tripletail, Atlantic	*Lobotes surinamensis*	3,755	3,448	0.0
Sea Catfishes	Ariidae	12,567	3,411	0.0
Puffers	Tetradontidae	4,997	3,394	0.0
Rays	*Rajiformes/Myliobatiformes*	19,400	3,383	0.0
Shark, Longfin Mako	*Isurus paucus*	4,037	3,083	0.0
Drums	Sciaenidae	4,864	2,267	0.0
Snapper, Dog	*Lutjanus jocu*	1,699	1,889	0.0
Rosefish, Blackbelly	*Helicolenus dactylopterus*	1,590	1,789	0.0
Scorpionfish, Spotted	*Scorpaena plumieri*	1,208	1,780	0.0
Snapper, Cubera	*Lutjanus cyanopterus*	1,476	1,603	0.0
Creolefish, Atlantic	*Paranthias furcifer*	2,193	1,546	0.0
Ray, Stingrays	*Rajiformes/Myliobatiformes*	4,953	1,360	0.0
Shark, Silky	*Carcharhinus falciformis*	4,152	1,357	0.0
Parrotfishes	Scaridae	1,207	1,192	0.0
Shark, Tiger	*Galeocerdo cuvier*	3,708	1,157	0.0
Bigeye	*Priacanthus arenatus*	1,964	1,149	0.0
Sand Perch	*Diplectrum formosum*	612	1,141	0.0
Grouper, Yellowmouth	*Mycteroperca interstitialis*	489	1,061	0.0
Pompano, African	*Alectis ciliaris*	795	971	0.0
Scorpionfish, Spinycheek	*Neomerinthe hemingwayi*	838	898	0.0
Eel, Conger	Congridae	1,004	876	0.0
Hind, Rock	*Epinephelus adscensionis*	425	791	0.0
Snapper, Caribbean Red	*Lutjanus purpureus*	816	749	0.0
Bass, Longltail	*Hemanthias leptus*	680	667	0.0
Triggerfish, Queen	*Balistes vetula*	582	599	0.0
Tuna, Skipjack	*Katsuwonus pelamis*	572	469	0.0
Lookdown	*Selene vomer*	680	467	0.0
Opah	*Lampris guttatus*	346	445	0.0
Squirrelfishes	Holocentridae	607	357	0.0
Runner, Rainbow	*Elagatis bipinnulata*	560	315	0.0
Eels, Snake	Ophichthidae	231	312	0.0
Sea Chubs	Kyphosidae	538	283	0.0
Tilefish, Sand	*Malacanthus plumieri*	166	244	0.0
Shark, Thresher	*Alopias vulpinus*	531	214	0.0
Jack, Horse-eye	*Caranx latus*	248	172	0.0
Graysby	*Cephalopholis cruentata*	64	117	0.0
Snapper, Schoolmaster	*Lutjanus apodus*	82	111	0.0
Shark, Bonnethead	*Sphyrna tiburo*	338	96	0.0
Pomfrets	Bramidae	82	78	0.0
Jack, Black	*Caranx lugubris*	139	76	0.0

Table 4. Recreational fishing landings for the GOM (ex Texas) and for Texas. GOM source: Marine Recreational Fisheries Statistics Survey (NMFS 2008a). Texas source: TDPW Recreational Fishery Survey. Data represents annual averages for the period 2000-2007. Data are listed in decreasing order by pounds landed for GOM (ex Texas).

Common Name	Scientific Name	GOM (ex Texas)		TX[1]	
		Number	Pounds	Number	
Drum, Red	*Sciaenops ocellatus*	2,792,750	13,135,765	263,650	
Seatrout, Spotted	*Cynoscion nebulosus*	10,701,120	13,038,549	996,409	
Sheepshead	*Archosargus probatocephalus*	1,687,532	4,518,621	74,479	
Snapper, Red	*Lutjanus campechanus*	963,290	3,688,532	48,479	
Grouper, Gag	*Mycteroperca microlepis*	483,139	3,541,098		
Mackerel, Spanish	*Scomberomorus maculatus*	1,819,391	2,748,731	5,912	
Mackerel, King	*Scomberomorus cavalla*	310,163	2,683,965	19,599	
Drum, Black	*Pogonias cromis*	580,911	2,597,909	79,005	
Dolphinfish	*Coryphaena hippurus*	372,576	2,013,998	4,250	
Other Fishes		1,589,419	1,961,374	193,326	
Pinfish	*Lagodon rhomboides*	6,514,709	1,806,657		
Mullet, Striped (Liza)	*Mugil cephalus*	1,284,518	1,741,879		
Grouper, Red	*Epinephelus morio*	251,695	1,678,793		
Snapper, Gray	*Lutjanus griseus*	931,691	1,661,350		
Seatrout, Sand	*Cynoscion arenarius*	2,945,563	1,641,332	170,108	
Grunt, White	*Haemulon plumierii*	1,791,559	1,573,515		
Amberjack, Greater	*Seriola dumerili*	84,915	1,538,839	1,024	
Runner, Blue	*Caranx crysos*	1,576,909	1,449,283		
Catfish, Saltwater	Aridae	495,949	829,716	30,938	2
Flounder, Southern	*Paralichthys lethostigma*	605,310	808,200	98,551	
Kingfish, Southern	*Menticirrhus americanus*	1,309,636	706,884		
Tuna, Little Tunny	*Euthynnus alletteratus*	95,608	683,238	599	
Sharks, Other		120,313	674,897	2,855	4
Tuna, Yellowfin	*Thunnus albacares*	11,898	547,291		
Trigerfishes/Filefishes	*Balistidae/Monacanthidae*	271,738	524,145	3,706	3
Tuna, Blackfin	*Thunnus atlanticus*	42,144	514,306		
Croaker, Atlantic	*Micropogonias undulatus*	1,194,087	502,732	135,537	
Jack, Crevalle	*Caranx hippos*	165,498	451,629		
Bluefish	*Pomatomus saltatrix*	238,659	435,699		
Mullets	Mugilidae	995,080	419,713		
Jacks	Carangidae	1,219,856	394,497		
Snapper, Vermilion	*Rhomboplites aurorubens*	325,648	337,055	1,497	
Sea Bass, Black	*Centropristis striata*	368,521	326,015		
Pompano, Florida	*Trachinotus carolinus*	174,807	296,499		
Kingfish, Gulf	*Menticirrhus littoralis*	376,409	252,827		
Snapper, Yellowtail	*Ocyurus chrysurus*	198,317	249,435		
Barracuda, Great	*Sphyraena barracuda*	24,446	236,967		
Flounder, Gulf	*Paralichthys albigutta*	151,897	206,754		
Snapper, Lane	*Lutjanus synagris*	183,166	175,191	1,728	
Groupers, Mycteropercid	*Mycteroperca sp.*	32,022	169,313		
Wahoo	*Acanthocybium solandri*	7,027	143,174		
Tuna/Mackerel, Other	Scombridae	31,695	125,450		
Snapper, Mutton	*Lutjanus analis*	17,540	112,078		
Catfish, Freshwater	Ictaluridae	89,435	108,681		
Pigfish	*Orthopristis chrysoptera*	360,687	101,005		
Wrasses	Labridae	55,471	99,018		
Sea Bass, Other	Serranidae	334,153	87,026		
Porgy, Red	*Pagrus pagrus*	82,803	81,325		
Porgies, Other	Sparidae	81,151	53,604		
Drum, Other	Sciaenidae	182,066	52,307		
Groupers, Epinephelid	*Epinephelus sp.*	5,669	38,242		
Skates and Rays	*Rajiidae/Myliobatiformes*	19,018	28,835		
Perch, Silver	*Bairdiella chrysoura*	188,194	26,521		
Mackerel, Atlantic Chub	*Scomber colias*	68,586	21,838		
Grunts	Haemulidae	152,354	19,070		
Snapper, Other	Scombridae	7,748	13,163		
Kingfish, Northern	*Menticirrhus saxatilis*	20,709	8,507		
Spot	*Leiostomus xanthurus*	68,546	5,018		
Puffers	Tetraodontidae	9,265	2,913		
Sharks, Dogfish		905	2,532		

Table 4. Continued.

Common Name	Scientific Name	GOM (ex Texas) Number	GOM (ex Texas) Pounds	TX[1] Number
Bass, Striped	*Morone saxatilis*	2,578	1,417	
Cod/Hake	Gadiformes	711	210	
Toadfishes	Batrachoididae	1,483	168	
Eels	Anguilliformes	8,573	147	
Searobins	Triglidae	2,847	98	
Flounder	Pleuronectiformes	8,179	80	
Other Temperate Basses	Moronidae	1,182	65	
Kingfishes	*Menticirrhus sp.*	47,026	0	

[1] TDPW also reports annual catches of 1,309 cobia (*Rachycentron canadum*) and 2,792 Atlantic Spadefish (*Chaetodipterus faber*)
[2] TDPW reports a single species of seawater catfish: gafftopsail catfish (*Bagre marinus*)
[3] TDPW reports annual catches for two species of shark: 1,780 Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) and 1,075 blacktip shark (*Carcharhinus limbatus*)
[4] TDPW reports a single species of triggerfish: gray triggerfish (*Balistes capriscus*)

Collectively, brown and white shrimp account for 53.2% (dollar value) of the entire GOM commercial fishery. Seven of the top ten commercially valuable species are shellfish: brown shrimp, white shrimp, eastern oyster, blue crab pink shrimp, Florida stone crab, and spiny lobster. None of these invertebrate species is taken recreationally and their importance to CWIS analysis stems solely from their commercial value.

In terms of dollar value, the Gulf menhaden is the fourth most important species in the commercial fishery. However, in terms of weight, this species is by far the dominant species in the GOM with average annual landings of nearly 1.1 billion pounds. This represents 71.6% of the total 1.5 billion pounds of biomass taken annually in the GOM commercial fishery all taxa combined. Menhaden are used primarily for the production of meal, oil, and soluables, while small quantities are used for bait (NMFS 2008a).

In terms of pounds landed, the red drum and spotted seatrout are the dominant species taken in the GOM (ex Texas) recreational fishery. Spotted seatrout numerically ranks first in the Texas recreational fishery with red drum second.

Fisheries Management Plan Species

Table 5 lists species and taxa as compiled by GMFMC (2004) for their current Fishery Management Plan (FMP). FMP's are developed for species under Federal management jurisdiction by regional Fishery Management Councils (FMC). FMPs are used to help manage the population in question and include comprehensive life-history and distributional data assessments. The FMP listing is provided in this report to denote species that are under constant FMC scrutiny. Data associated with the FMP listing augments the commercial and recreational target species listing and may be used to determine the vulnerability of individual species to offshore CWIS.

The FMPs are for red drum, reef fish (41 species), coastal migratory pelagic fish (3 species), shrimp (brown, white, pink, and royal red), stone crab (2 species) and spiny lobster (2 species). Also listed in GMFMC (2004) are fishery resources not under Council FMPs. These include highly migratory species (billfish and tuna) and sharks. Additionally, nine species of nearshore fish and shellfish not included in Gulf Council's FMPs comprise the majority of commercial and recreational harvest managed in State waters. The GSMFC, in coordination with the individual states, have completed FMPs for menhaden, flounder, spotted seatrout, Spanish mackerel, striped bass, blue crab, oyster, black drum, and stripped mullet (GMFMC 2004).

Collectively, the GMFMC and GSMFC have developed FMPs for seven invertebrate species that are among the top eight commercially valuable taxa taken in the northern GOM: brown shrimp, white shrimp, pink shrimp, Florida stone crabs, blue crab, eastern oyster, and spiny lobster (see Table 3). GSMFC FMPs are also available for red drum (recreational fishery: 4th in GOM, 2nd in Texas waters), red snapper (10th in commercial fishery), two of the more politically sensitive species in the GOM.

Table 5. Species listed in the Essential Fish Habitat Amendment to Gulf of Mexico Fishery Management Plans. Source: GMFMC (2004).

FMP	Common name	Scientific Name
Red Drum (1)	Drum, Red	*Sciaenops ocellatus*
Reef Fish (43)	**Balistidae - Triggerfishes (1)**	
	Triggerfish, Gray	Balistes capriscus
	Carangidae - Jacks (4)	
	Amberjack, Greater	*Seriola dumerili*
	Amberjack, Lesser	*Seriola fasciata*
	Jack, Almaco	*Seriola rivoliana*
	Rudderfish, Banded	*Seriola zonata*
	Labridae - Wrasses (1)	
	Hogfish	Lachnolaimus maximus
	Lutjanidae - Snappers (14)	
	Snapper, Queen	*Etelis oculatus*
	Snapper, Mutton	*Lutjanus analis*
	Snapper, Schoolmaster	*Lutjanus apodus*
	Snapper, Blackfin	*Lutjanus buccanella*
	Snapper, Red	*Lutjanus campechanus*
	Snapper, Cubera	*Lutjanus cyanopterus*
	Snapper, Gray	*Lutjanus griseus*
	Snapper, Dog	*Lutjanus jocu*
	Snapper, Mahogany	*Lutjanus purpureus*
	Snapper, Lane	*Lutjanus synagris*
	Snapper, Silk	*Lutjanus vivanus*
	Snapper, Yellowtail	*Ocyurus chrysurus*
	Wenchman	*Pristipomoides aquilonaris*
	Snapper, Vermilion	*Rhomboplites aurorubens*
	Malacanthidae - Tilesfishes (5)	
	Tilefish, Goldface	*Caulolatilus chrysops*
	Tilefish, Blackline	*Caulolatilus cyanops*
	Tilefish, Anchor	*Caulolatilus intermedius*
	Tilefish, Blueline	*Caulolatilus microps*
	Tilefish, Golden	*Lopholatilus chamaeleonticeps*
	Serrinidae - Groupers (18)	
	Sand Perch, Dwarf	*Diplectrum bivittatum*
	Sand Perch	*Diplectrum formosum*
	Hind, Rock	*Epinephelus adscensionis*
	Hind, Speckled	*Epinephelus drummondhayi*
	Grouper, Yellowedge	*Epinephelus flavolimbatus*
	Hind, Red	*Epinephelus guttatus*
	Grouper, Goliath	*Epinephelus itajara*
	Grouper, Red	*Epinephelus morio*
	Grouper, Misty	*Epinephelus mystacinus*

Table 5. Continued.

FMP	Common name	Scientific Name
	Grouper, Warsaw	*Epinephelus nigritus*
	Grouper, Snowy	*Epinephelus niveatus*
	Grouper, Nassau	*Epinephelus striatus*
	Grouper, Marbled	*Dermatolepis inermis*
	Grouper, Black	*Mycteroperca bonaci*
	Grouper, Yellowmouth	*Mycteroperca interstitialis*
	Gag	*Mycteroperca microlepis*
	Scamp	*Mycteroperca phenax*
	Grouper, Yellowfin	*Mycteroperca venenosa*
Coastal Migratory Pelagic (3)	Mackerel, King	*Scomberomorus cavalla*
	Mackerel, Spanish	*Scomberomorus maculatus*
	Cobia	*Rachycentron canadum*
Shrimp (4)	Shrimp, Brown	*Farfantepenaeus aztecus*
	Shrimp, White	*Farfantepenaeus setiferus*
	Shrimp, Pink	*Farfantepenaeus duorarum*
	Shrimp, Royal Red	*Pleoticus robustus*
Stone Crab (2)	Crab, Florida Stone Claws	*Menippe mercenaria*
	Crab, Florida Stone Claws (Ceder Key N)	*Menippe adina*
Spiny Lobster (2)	Lobster, Caribbean Spiny	*Panulirus argus*
	Lobster, Slipper	*Scyllarides squammosus*

ASSESSMENT MODELS AND PARAMETERS

Assessment models and their input parameters provide a quantitative basis for estimating the extent to which entrainment losses impact fishery populations. In this report we draw on the USCG/MARAD assessment technique and augment it with techniques presented in more recently published research.

The USCG/MARAD assessment approach makes use of a forward-projecting Equivalent Adult Model (EAM), as described in EPA (2002) and EPRI (2004, 2005), to evaluate the expected levels of impacts from entrainment. It is assumed that entrained eggs and larvae suffer 100% mortality. With the EAM approach, entrainment losses at any given stage (it is assumed that only egg and larvae stages are entrained) are simply multiplied by the fraction of fish at that stage that would have otherwise been expected to survive had they not been lost to entrainment. A commonly expressed intermediate (and sometimes final) endpoint measure of loss used in many of the GOM LNG assessments is termed age-1 equivalents; or, the number of entrained fish (eggs and larvae) that would have survived to age-1 had they not been entrained (e^2M 2005). Another endpoint is the production foregone, or the estimated biomass loss to the ecosystem or fishery that results from egg and larval entrainment.

In order to implement the EAM, the seawater intake rate and several pieces of fishery-related information must be known or calculated: egg and larval densities for the target species, entrainment loss, the instantaneous natural daily mortality rate of the species, and stage duration.

1. **Egg and larvae densities** in the vicinity of the seawater intake structure must be known in order to calculate entrainment loss.

2. **Entrainment loss** is the total number of eggs and larvae that are lost to seawater intake. The entrainment loss is calculated by multiplying the total volume of seawater withdrawn over some specified period of time, times the density of egg and larvae in the water column during that time. The conventional time frame for calculating entrainment loss is one year.

3. The **instantaneous natural daily mortality rate** M (d^{-1}) for each stage through which the fish passes from spawning through the age equivalent of interest. For age-1 equivalents this includes mortality rates for the egg, larval, post-larval, and early juvenile stages. For adult equivalents mortality rates are required for all intervening age classes.

4. **Stage duration** is the amount of time a fish remains within a specific stage and is subject to the daily mortality rate associated with that stage. The egg stage duration for many fish is about one day. In contrast, the larval stage may last for many days and the daily mortality rate must be applied for each day that the fish remains within that stage.

The instantaneous natural daily mortality rate M (d^{-1}) times the stage duration (d) yields the stage mortality Z, which is dimensionless. That is the total mortality across the entire stage. Once a species passes into juvenile stages and beyond, forward-projecting EAMs typically deal with annual stage mortality by age class. Forward-projecting EAMs must also incorporate estimates of annual fishing mortality by age class for those species vulnerable to commercial or recreational fisheries.

EPRI (2004, 2005) and Gallaway et al. (2007) noted that the forward-projecting EAM does not take into account density-dependent processes that might also contribute additional mortality to the species and proposed an alternative approach. For example, the red snapper (*Lutjanus campechanus*) is one of the most important commercial and recreational species in the GOM. Although the eggs and larval stage of red snapper are planktonic, once they transform into juveniles, they settle to the seafloor where they inhabit low-relief, hard substrate. This hard substrate provides shelter and is essential for survival. This is where the fish spend most of the first year of life. Yet the amount of hard substrate in the GOM is limited and, if overcrowding occurs, the overflow organisms are subject to high levels of open-water predation and low survival. The level of mortality is thus density-dependent. The EAM model does not account for this and if density-dependent mortality does occur at life stages following those subject to entrainment, the losses associated with entrainment using forward-projecting EAMs will be overestimated.

EPRI (2004, 2005) and Gallaway et al. (2007) propose using a fecundity-hindcasting model (FHM) to estimate entrainment loss under these circumstances. Using the same parameter values as the EAM (daily mortality, stage duration, entrainment loss and egg/larval densities), the FHM projects backward and converts the total number of entrained eggs and larval to equivalent eggs. That is, adjusting for natural mortality throughout the planktonic egg and larval stages, the model converts actual entrainment loss to the number of original eggs that would have been required to account for that total loss. The number of equivalent eggs is then evaluated in terms of the number of female spawners; i.e., fish if egg-laying age that would have been required to produce that number of eggs or to the egg stock size. The number of female spawners represents the number of adult females lost to entrainment annually and is an endpoint measure of the impact.

If the FHM is used, a fifth parameter is required.

5. **Fecundity** is the number of eggs produced annually or over a lifetime by a female adult. Fecundity is age or size dependent, with older, larger females typically producing more eggs than younger females.

Fecundity may actually be a viable parameter in forward-projecting EAMs if it is the goal of the assessment to convert loss into reproductive output.

GENERAL LIFE-HISTORY PARAMETER VALUES

The prerequisite for the application of any CWIS assessment model is to obtain value estimates for the four key life-history parameters: instantaneous daily egg mortality (d^{-1}), egg duration (d), instantaneous daily larval mortality (d^{-1}), larval stage duration (d) for the species in question. If fecundity data for a particular species is available in the literature, FHMs can be applied. If forward-projecting EAMs are used additional life-history data is needed for older age cohorts through adulthood including fishing and natural mortality by age.

Contingent with minimum requirements, LGL conducted an exhaustive search of the scientific literature and compiled four tables summarizing the available data for all species of marine fish (Tables 6-9). More detailed life-history data is presented in Appendix D.

It should be noted that daily morality rates and duration times in egg and larval stages are strongly influenced by temperature, size, and growth rate (Morse 1989, Pepin 1991). The interactive relationship among these parameters is complex and at times conflicting (Pepin 1991). Although a detailed synopsis is beyond the scope of this report, a comprehensive review of the subject is provided in EPRI (2005).

Table 6. Natural mortality rates for eggs of marine fish. Compiled from McGurk (1986), Houde (1987), Pepin (1991), with additions. List may not include some selected species described in greater detail within Species Profiles provided in Appendix D. Water temperature was recorded at the time of the survey.

Family	Common Name	Scientific Name	Instantaneous Daily Mortality M (d^{-1})	Temp (°C)	Source
Engraulidae	Bay Anchovy	*Anchoa Mitchilli*	0.69		Houde (1987)
			1.94		Purcell et al. (1994)
	Argentinean anchovy	*Engraulis anchoita*	0.6	12.5	Ciechomski (1973)
	Japanese anchovy	*Engraulis japonica*	0.33	19.4	Hiyashi (1966)
	Cape anchovy	*Engraulis capensis*	0.25	18.0	Armstrong et al. (1988)
	Northern anchovy	*Engraulis mordax*	0.23	15.0	Smith et al. (1989)
			0.39	15.0	Lo (1985)
			0.13-0.39		Lo (1986)
	European anchovy	*Engraulis encrasicolus*	0.47-1.089		Garcia and Palomera (1996)
	Peruvian anchovy	*Engraulis ringens*	1.21	17.0	Smith et al. (1989)
			0.91	17.0	Santander et al. (1983)
Clupeidae	Atlantic herring	*Clupea harangus*	0.05		Houde (1987)
	Round herring	*Etremeus teres*	1.09	22.7	Houde (1977a)
	Scaled sardine	*Harengula jaguana*	3.64	25.8	Houde (1977c)
	Atlantic thread herring	*Opisthonema oglinum*	2.57	26.4	Houde (1977b)
	California sardine	*Sardinops caerulea*	0.31	14.0	Smith (1973)
	Japanese sardine	*Sardinops melanostica*	0.33	15.1	Nakai and Hattori (1962)
			0.50		Tanaka (1974)
	Pacific sardine	*Sardinops sagax*	2.21	17.0	Smith et al. (1989)
	European sprat	*Sprattus sprattus*	0.04		Alheit et al. (1987)
Gadidae	Atlantic cod	*Gadus morhua*	0.14		Mountain et al. (2003)
			0.03-0.04		Daan (1981)
			0.14-0.22		Heesen and Rijnsdorp (1989)
			0.205		Land et al. (1990)
			0.05		Houde (1987)
			0.10		Fossum (1988)
	Haddock	*Melanogrammus aeglefinus*	0.21-0.54	5.0	Koslow et al. (1985)
			0.12		Mountain et al. (2003)
			0.10		Saville (1956)
Carangidae	Jack mackerel	*Trachurus symmetricus*	1.64	15.0	Farris (1961)
Sparidae	Australian snapper	*Chrysophrys auratus*	0.3-1.01		Crossland (1980)
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.4984		Diamond et al. (1999)
Labridae	Cunner	*Tautogolabrus adspersus*	0.67	18.0	Williams and Williams (1973)
Scombridae	Atlantic mackerel	*Scomber scombrus*	0.56		Ware and Lambert (1985)
			0.40	15.4	
			0.52	17.5	
			0.41	15.7	
			0.13		Sette (1943)
			0.88		Berrien et al. (1981)
			0.05-0.16		Thompson (1989)
Pleuronectidae	Plaice	*Pleuronectes platessa*	0.039	3.2	Harding et al. (1978)
			0.140	6.6	
			0.084	7.7	
			0.063	6.8	
			0.055	5.6	
			0.090	4.8	
			0.074	6.5	
			0.017	1.5	
			0.074	6.0	
			0.12	7.8	
			0.07-0.17		Heesen and Rijnsdorp (1989)
			0.096		Land et al. (1990)
			0.11-0.20		Coombs et al. (1990)
			0.15-0.29		Dickey-Collas et al. (2003)
Soleidae	Sole	*Solea solea*	1.00	10.4	Riley (1974)
			0.60	13.6	
			0.46		Beek (1989)
			0.40-0.61		Land (1991)
			0.2		Horwood (1992)

Table 7. Egg duration (time to hatch) for eggs of marine fish. Compiled from Pauly and Pullin (1988), with additions. Water temperature was recorded at the time of the survey.

Family	Common name	Scientific Name	Duration (days)	Temp (°C)	Source
Clupeidae	Round herring	*Etrumeus teres*	1.50	20.5	Jones et al. (1978)
			2.00	24.0	
			2.08	21.5	
			5.63	11.0	
	Atlantic menhaden	*Brevoortia tyrannus*	2.00	17.5	
	European sprat	*Sprattus sprattus*	11.50	4.3	Thompson et al. (1981)
			9.33	5.2	
			7.83	6.0	
			6.75	7.0	
			5.79	8.0	
			5.17	8.9	
			4.43	9.7	
			4.06	10.6	
			3.65	11.4	
			3.36	12.2	
			2.95	13.2	
			2.77	13.7	
			2.48	14.8	
			2.32	15.6	
			2.17	16.5	
			2.13	17.4	
			1.88	18.4	
			1.80	19.1	
			1.76	20.0	
	African pilchard	*Sardinops ocellta*	3.70	11.0	King (1977)
			1.75	16.0	
	Madagascar sardine	*Dussumieria hasselti*	1.50	28.5	Delsman (1972)
Chanidae	Milkfish	*Chanos chanos*	1.06	29.5	Liao et al. (1979)
			1.19	28.2	Chaudhuri et al. (1978)
			1.04	28.2	
Ictaluridae	Bartail flathead	*Platycephalus indicus*	1.00	25.0	Breder and Rosen (1966)
Phycidae	Spotted hake	*Urophycis regius*	2.38	22.5	Hardy (1978)
	Red hake	*Urophycis chuss*	1.25	21.1	
	Fourbeard rockling	*Enchelyopus cimbrius*	5.40	13.0	
Merluccidae	European hake	*Merluccius merluccius*	10.00	9.1	Breder and Rosen (1966)
	Silver hake	*Merluccius bilinearis*	2.00	21.0	Hardy (1978)
	Offshore hake	*Merluccius albidus*	7.00	9.8	
			4.50	15.0	
Gadidae	Atlantic cod	*Gadus morhua*	10.50	8.3	Breder and Rosen (1966)
	Pollack	*Pollachius virens*	9.00	9.4	
	Haddock	*Melanogrammus aeglefinus*	15.00	2.8	
			13.00	5.0	
	Blue whiting	*Micromesistius poutassou*	11.50	8.0	Russell (1976)
			4.00	10.5	
Mugilidae	Stripped mullet	*Mugil cephalus*	1.54	24.0	Kuo et al. (1973)
			2.04	22.0	
	Grey mullet	*Mugil macrolepis*	0.96	27.5	Sebastian and Nair (1975)
Fistulariidae	Red cornetfish	*Fistularia serrata*	4.00	28.5	Delsman (1972)
Triglidae	Gray gurnard	*Eutrigla gurnardus*	5.00	15.0	Russell (1976)
		Lepidotrigla japonica	2.29	20.0	Breder and Rosen (1966)
	Bluefin gurnard	*Chelidonichthys kumu*	7.00	9.0	
	Northern searobin	*Prionotus carolinus*	2.50	22.0	Fritzsche (1978)
			3.71	20.5	
Serranidae	Greasy grouper	*Epinephelus tauvina*	1.27	28.5	Hussain et al. (1975)
			1.00	27.0	Chen et al. (1977)
	Red hind	*Epinephelus guttatus*	1.12	26.5	Heemstra and Randall (1993)
	Honeycomb grouper	*Epinephelus merra*	1.06	27.6	Jagadis et al. (2006)
	European sea bass	*Dicentrarchus labrax*	4.67	13.0	Barnabe (1976)
			2.50	15.0	Russell (1976)
			2.29	17.0	

Table 7. Continued.

Family	Common name	Scientific Name	Duration (days)	Temp (°C)	Source
Serranidae	Black sea bass	*Centropristes striatus*	5.00	10.0	Breder and Rosen (1966)
			5.00	10.0	Hardy (1978)
			5.00	15.0	
			3.13	15.0	
			3.13	16.0	
			1.58	23.0	
	Japanese sea perch	*Lateolabrax japonicus*	4.50	13.0	Breder and Rosen (1966)
Pomatomidae	Bluefish	*Pomatomus saltatrix*	1.96	20.0	Hardy (1978)
Carangidae		*Decapterus kurra*	0.50	28.5	Delsman (1972)
	Shortfin scad	*Decapterus macrosoma*	0.38	28.5	Delsman (1972)
	Japanese amberjack	*Seriola quinqueradiata*	2.08	21.0	Kuronuma and Fukusho (1984)
Coryphaenidae	Dolphinfish	*Coryphaena hippurus*	2.00	24.5	Johnson (1978)
Leiognathidae	Silver ponyfish	*Leiognathus nuchalis*	1.56	23.0	Breder and Rosen (1966)
Lutjanidae	Bluestripe snapper	*Lutjanus kasmira*	0.75	26.4	Suzuki and Hioki (1979)
Lethrinidae	Longspine emperor	*Lethrinus nematacanthus*	1.63	20.4	Breder and Rosen (1966)
Sparidae	Scup	*Stenotomus chrysops*	1.67	22.0	Johnson (1978)
			1.67	22.2	Breder and Rosen (1966)
	Sheepshead	*Archosargus probatocephalus*	1.67	25.5	
	W. Australian pink snapper	*Pagrosomus auratus*	1.88	18.0	
	Kurodai	*Mylio macrocephalus*	2.50	19.3	Fukuhara (1977)
	Slivery black sea bream	*Acanthopagrus cuvieri*	1.66	21.0	Hussain et al. (1981)
Nemipteridae		*Nemipterus variegatus*	1.17	24.0	Breder and Rosen (1966)
Sparidae	Pinfish	*Lagodon rhomboides*	2.00	18.0	Cardeilac (1976)
Oplegnathidae	Stripped beakfish	*Oplegnathus fasciatus*	1.50	21.0	Breder and Rosen (1966)
Sciaenidae	Silver perch	*Bairdiella chrysoura*	0.75	27.0	Johnson (1978)
			1.88	20.0	
	Black drum	*Poganias chromis*	1.00	20.0	
	Northern kingfish	*Menticirrhus saxatilis*	2.00	20.5	
			2.08	20.0	Breder and Rosen (1966)
	White croaker	*Nibea argentata*	0.92	23.0	
Labridae	Cunner	*Tautogalabrus adsperus*	1.67	21.5	Fritzsche (1978)
	Tautog	*Tautoga onitis*	1.81	21.1	Breder and Rosen (1966)
	Cupid wrasse	*Thalassoma cupido*	1.50	23.3	
Scaridae	Japanese parrotfish	*Calotomus japonicus*	1.00	25.0	Breder and Rosen (1966)
Trachinidae	Greater weever	*Trachinus draco*	4.50	16.8	Russell (1976)
Ephippidae	Atlantic spadefish	*Chaetodipterus faber*	1.00	27.0	Johnson (1978)
Acanthuridae	Convict surgeonfish	*Acanthurus triostegus*	1.08	24.0	Breder and Rosen (1966)
Siganidae	Streamlined spinefoot	*Siganus argenteus*	1.04	26.5	Burgan and Zseleczky (n.d.)
Sphyraenidae	Red barracuda	*Sphyraena pinguis*	1.13	23.7	Breder and Rosen (1966)
Gempylidae	Snoek	*Thyrsites atun*	2.08	18.5	Breder and Rosen (1966)
Trichiuridae	Curlassfishes	*Trichiurus sp.*	2.00	28.5	Delsman (1972)
Scombridae	Atlantic mackerel	*Scomber scombrus*	7.38	7.4	Russell (1976)
			2.06	21.0	
			3.20	17.8	Lockwood et al. (1981)
			3.43	17.0	
			3.62	16.1	
			4.00	15.1	
			4.43	14.4	
			4.94	13.4	
			5.62	12.6	
	Spanish mackerel	*Scomberomorus maculatus*	1.04	25.0	Breder and Rosen (1966)
			0.65	29.0	Fritzsche (1978)
			1.02	25.5	
	Pacific chub mackerel	*Scomber japonicus*	2.04	19.5	Fritzsche (1978)
			2.08	20.0	
			1.375	23.0	Hunter and Kimbrell (1980)
	Yellowfin tuna	*Thunnus albacares*	1.85	18.7	Harada et al. (1980)
			1.40	24.4	
			1.34	30.1	
			0.83	24.0	Margulies et al. (2007)
			1.17	29.5	

Table 7. Continued.

Family	Common name	Scientific Name	Duration (days)	Temp (°C)	Source
Scombridae	Bigeye tuna	*Thunnus obesus*	0.88	28.8	Fritzsche (1978)
	Skipjack tuna	*Katsuwonus pelamis*	1.10	26.7	Inoue et al. (1974)
	Bluefin Tuna	*Thunnus thynnus*	3.00		Muus and Nielsen (1999)
Nomeidae	Silver warehou	*Seriolella punctata*	6.08	11.5	Grimes and Robertson (1981)
Stromateidae	Butterfish	*Peprilus triacanthus*	3.00	14.6	Martin and Drewery (1978)
Scophthalmidae	Black Sea turbot	*Scophthalmus maeoticus*	7.00	11.5	Martin and Drewery (1978)
			5.42	13.5	
			5.29	14.0	
			5.17	14.2	
			5.00	15.0	
			4.71	16.3	
			3.00	17.7	
	Turbot	*Scophthalmus maximus*	9.50	10.0	Russell (1976)
			7.00	12.0	
			5.00	14.5	
	Topknot	*Zeugopterus punctatus*	3.00	14.5	
Paralichthyidae	Summer flounder	*Paralichthys dentatus*	2.33	22.9	Martin and Drewery (1978)
			3.06	17.5	
			5.92	9.1	
Pleuronectidae	Sand dab	*Limanda limanda*	7.00	9.0	Russell (1976)
			12.00	7.0	
			3.00	10.0	
	Lemon sole	*Microstomus kitt*	5.50	15.3	
			8.80	8.8	
			6.00	6.0	
	Witch flounder	*Glyptocephalus cynoglossus*	8.00	8.6	
	Atlantic halibut	*Hippoglossus hippoglossus*	16.00	6.0	
	Stone flounder	*Kareius bicoloratus*	9.00	5.0	Yusa (1979)
Ostraciidae	Cowfish	*Lactophrys quadricornis*	2.00	27.3	Breder and Rosen (1966)

Table 8. Natural mortality rates for larvae of marine fish. Compiled from McGurk (1986), Morse (1989), Pepin (1991), Houde and Zastrow (1993), with additions. Water temperature was recorded at the time of the survey.

Family	Common Name	Scientific Name	Instantaneous Daily Mortality M (d^{-1})	Temp (°C)	Source
Engraulidae	Bay anchovy	*Anchoa mitchilli*	0.32	29.0	Leak and Houde (1987)
			0.45	24.4	
			0.30	28.1	
			0.42	30.7	
			0.375	27.0	Houde and Zastrow (1993)
	Japanese anchovy	*Engraulis japonica*	0.30	17.0	Hiyashi (1966), Zweifel and Lasker (1976)
	European anchovy	*Engraulis encrasicolus*	0.17-0.58		Garcia and Palomera (1996)
			0.432		Coombs et al. (2003)
			0.447		
	Northern anchovy	*Engraulis mordax*	0.22	15.5	Zweifel and Smith (1981)
			0.190	16.0	Houde and Zastrow (1993)
Clupeidae	Atlantic herring	*Clupea harengus*	0.04	8.0	Lough et al. (1981)
			0.061-0.074	7.0	Henderson et al. (1984)
			0.10		Das (1968), Laurence (1979)
			0.06		
			0.11		
			0.14		Dragesund and Nakken (1971a), Laurence (1979)
			0.46		Dragesund and Nakken (1971b), Laurence (1979)
			0.04		Lough et al. (1981)
			0.06		Henderson et al. (1984)
			0.07		Laurence (1979)
			0.0873		Morse (1989)
	Pacific herring	*Clupea pallasi*	0.09	11.0	McGurk (1987)
			0.09	12.0	
			0.31	11.0	
			0.06	10.0	
			0.41		Stevenson (1962), McGurk, (1986)
			0.25		
			0.09		Iizuka (1966), McGurk (1986)
			0.12		
	Amercian shad	*Alosa sapidissima*	0.21	21.0	Houde and Zastrow (1993)
	Round herring	*Etrumeus teres*	0.13	24.0	Houde (1977a)
	Scaled sardine	*Harengula jaguana*	0.28	26.0	Houde (1977c)
	Atlantic thread herring	*Opisthonema oglinum*	0.21	26.0	Houde (1977b)
			0.26	26.0	
	Spanish sardine	*Sardinella aurita*	0.46	23.0	Conand and Fagetti (1971), Conand (1977)
	Japanese sardine	*Sardinops melanostica*	0.10	15.1	Nakai and Hattori (1962)
	Pacific sardine	*Sardinops sagax*	0.10		Lenarz (1973), Zweifel and Lasker (1976)
Myctophidae	Glacier lanternfish	*Benthosema glaciale*	0.0780		Morse (1989)
	Madeira lanternfish	*Ceratoscopelus maderensis*	0.223		
Phycidae	Hakes	*Urophycis spp.*	0.180		Morse (1989)
	Fourbeard rockling	*Enchelyopus cimbrius*	0.123		Morse (1989)
Merluccidae	Silver hake	*Merluccius bilinearis*	0.130		Morse (1989)
	Offshore hake	*Merluccius albidus*	0.189		
Gadidae	Haddock	*Melanogrammus aeglefinus*	0.11		Jones (1973), Laurence (1979)
			0.0674		Morse (1989)
	Atlantic cod	*Gadus morhua*	0.0409		Morse (1989)
			0.105	7.5	Houde and Zastrow (1993)
	Blue whiting	*Micromesistius poutassou*	0.15		Bailey (1974), Laurence (1979)
Lophiidae	Goosefish	*Lophius americanus*	0.261		Morse (1989)
Scomberesocidae	Pacific saury	*Cololabis saira*	0.07	14.5	Watanabe and Lo (1989)
Scorpaenidae	Rockfishes	*Sebastes sp.*	0.04	7.0	Anderson (1984)
			0.04	6.8	
			0.06	8.8	
			0.13	11.5	
			0.225		Morse (1989)
Moronidae	Stripped bass	*Morone saxatilis*	0.170	17.0	Houde and Zastrow (1993)
Pomatomidae	Bluefish	*Pomatomus saltatrix*	0.312		Morse (1989)
Carangidae	Jack mackerel	*Trachurus symmetricus*	0.28	15.0	Hewitt et al. (1985)
			0.18	15.0	Hewitt (1981)
	Atlantic bumper	*Chloroscombrus chrysurus*	0.17-0.62		Leffler and Shaw (1992)
			0.20-0.37		Comyns et al. (2003)

Table 8. Continued.

Family	Common Name	Scientific Name	Instantaneous Daily Mortality M (d^{-1})	Temp (°C)	Source
Lutjanidae	Red snapper	*Lutjanus campechanus*	0.24		Gallaway et al. (2007)
	Vermillion snapper	*Rhomboplites aurorubens*	0.19-0.29		Comyns et al. (2003)
Sparidae	Sea bream	*Archosargus rhomboidalis*	0.18	24.0	Chavance et al. (1984)
			0.43	26.0	Crecco et al. (1983)
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.198		Morse (1989)
	Red drum	*Sciaenops ocellatus*	0.521	28.5	Comyns et al. (1991)
			0.3009		Comyns (1997)
	Spotted seatrout	*Cynoscion nebulosus*	0.500	28.0	Peebles and Tolley (1988)
Labridae	Cunner	*Tautogalabrus adsperus*	0.282		Morse (1989)
Pholidae	Rock gunnel	*Pholis gunnellus*	0.0236		Morse (1989)
Ammodytidae	Sand lances	*Ammodytes spp.*	0.0303		Morse (1989)
Scombridae	P. chub mackerel	*Scomber japonicus*	0.32	18.0	Watanabe (1970)
	Atlantic mackerel	*Scomber scombrus*	0.38	15.4	Ware and Lambert (1985)
			0.53	15.7	
			0.71	17.3	
			0.198		Morse (1989)
			0.35		Kendall and Gordon (1981)
	King mackerel	*Scomberomorus cavalla*	0.83		Grimes et al. (1990)
	Spanish mackerel	*Scomberomorus maculatus*	0.68		unpubl data cited in Allman and Grimes (1998)
	Little tunny	*Euthynnus alletteratus*	0.72		Allman and Grimes (1998)
			0.95		
	Yellowfin tuna	*Thunnus albacares*	0.27-0.42		Grimes and Lang (1992)
			0.16-0.45		Lang et al. (1994)
	Southern buefin tuna	*Thunnus maccoyi*	0.66		Jenkins and Davis (1990)
Stromateidae	Butterfish	*Peprilus triacanthus*	0.255	14.6	Morse (1989)
Pleuronectidae	Plaice	*Pleuronectes platessa*	0.06	6.0	Harding and Talbot (1973)
			0.06		Bannister et al. (1974), Ryland (1966)
	Gulf Stream flounder	*Citharichthys arctifrons*	0.215		Morse (1989)
	Smallmouth flounder	*Etropus microstomus*	0.242		Morse (1989)
	Summer flounder	*Paralichthys dentatus*	0.158		Morse (1989)
	Fourspot flounder	*Paralichthys oblongus*	0.205		Morse (1989)
	Windowpane flounder	*Scophthalmus aquosus*	0.136		Morse (1989)
	Amercian plaice	*Hippoglossoides platessoides*	0.079		Morse (1989)
	Witch flounder	*Glyptocephalus cynoglossus*	0.061		Morse (1989)
	Yellowtail flounder	*Limanda ferruginea*	0.142		Morse (1989)
	Winter flounder	*Pseudopleuronectes americanus*	0.12	14.5	Pearcy (1962)
			0.230	8.5	Houde and Zastrow (1993)

Table 9. Larval duration for marine fish. Compiled from Houde and Zastrow (1993), with additions. Water temperature was recorded at the time of the survey.

Family	Common Name	Scientific Name	Duration (days)	Temp (°C)
Engraulidae	Bay anchovy	*Anchoa mitchilli*	32.4	27
	Bigeye anchovy	*Anchoa lamprotaenia*	34.0	26
	Cape anchovy	*Engraulis capensis*	47.4	18
	European anchovy	*Entraulis encrasicolus*	36.7	22.8
	Japanese anchovy	*Engraulis japonica*	47.1	22
	Northern anchovy	*Engraulis mordax*	34.8	14.5
	Peruvian anchovy	*Engraulis ringens*	74.3	17.5
Clupeidae	Atlantic herring	*Clupea harengus*	160.6	11.5
	European pilchard	*Sardina pilchardus*	40.3	21.3
	Japanese sardine	*Sardinops melanostictus*	42.0	16
	Pacific sardine	*Sardinops caeruleus*	41.8	15.6
			43.8	16.6
Chanidae	Milkfish	*Chanos chanos*	43.5	27
Merculliidae	Pacific hake	*Merluccius productus*	88.0	13
Gadidae	Atlantic cod	*Gadus morhua*	100.9	7.5
	Haddock	*Melanogrammus aeglefinus*	127.7	6.5
	Walleye pollock	*Theragra chalcogramma*	108.3	7
Osmeridae	Capelin	*Mallotus villosus*	150.4	5.5
Atherinopsidae	Atlantic silverside	*Menidia menidia*	35.4	20
	California grunion	*Leuresthes tenuis*	44.2	18
	Tidewater silverside	*Menidia peninsulae*	41.0	25
Nemipteridae	Threadfin bream	*Scolopsis dubious*	19.0	26.5
Moronidae	European seabass	*Dicentrarchus labrax*	45.6	16.5
	Stripped Bass	*Morone saxatilis*	33.0	17
	White perch	*Morone americana*	84.5	17
Apogonidae	Cardinalfishes	*Apogon sp.*	20.4	26.5
	Five-lined cardin alfish	*Cheilodipterus quinquelineata*	23.1	26.5
Haemulidae	Grunts	*Haemulon spp.*	19.6	26.7
Sparidae	Gilthead seabream	*Sparus aurata*	49.5	17.5
	Red seabream	*Pagrus major*	46.6	20
	Sea bream	*Archosargus rhomboidalis*	21.0	26
Sciaenidae	Red drum	*Sciaenops ocellatus*	22.4	26.5
	Spotted seatrout	*Cynoscion nebulosus*	19.4	28
Chaetodontidae	Copperband butterflyfish	*Chelmon rostratus*	25.5	26.5
Pomacentridae	Anemonefish	*Amphiprion sp.*	13.7	29.8
	Blue-head damelfish	*Glyphidodontops rollandi*	23.1	26.5
	Damselfish	*Chromis spp.*	27.3	29.2
	Damselfish	*Chrysiptera spp.*	18.9	29.8
	Damselfish	*Dascyllus spp.*	22.5	29.4
	Damselfish	*Dischistodus spp.*	16.1	29.8
	Damselfish	*Pomacentrus spp.*	19.8	28.8
	Damselfish	*Stegastes spp.*	23.3	28.7
	Lagoon damselfish	*Hemiglyphidodon plagiometopon*	18.0	29.8
	Sergeant fishes	*Abudefdul spp.*	23.1	28.7
	Staghorn damselfish	*Amblyglyphidodon curacao*	13.1	29.8
Labridae	Bluestreak wrasse	*Labroides dimidiatus*	26.0	26.5
	California sheepshead	*Semicossyphus pulcher*	52.2	15
	Coral damselfish	*Neopomacentrus nemurus*	19.2	29.8
	Damselfish	*Paraglyphidodon spp.*	19.0	29.8
	Dapple coris	*Coris variegata*	29.7	26.5
	Pinstriped wrasse	*Halichoeres hoeveni*	46.5	26.1
	Razorfish	*Xyrichtys sp.*	88.5	25.7
	Threadfin wrasse	*Cirrhilabrus temminckii*	28.0	26.5
	Wrasses	*Pseudojulis sp.*	55.0	25.7
	Wrasses	*Thalassoma spp.*	64.4	26
Blenniidae	Blennies	*Petroscirtes spp.*	24.5	26.5
Ammodytidae	Amercian sand lance	*Ammodytes americanus*	159.1	5
Gobiidae	Clown gobies	*Gobiodon spp.*	30.2	26.5
	Gobies	*Paragobiodon spp.*	38.8	26.5
	Naked goby	*Gobiosoma bosci*	30.9	26
	Old glory	*Amblygobius rainfordi*	40.3	26.5
Ephippidae	Spadefishes	*Chaetodon spp.*	37.0	26.5

Table 9 Continued.

Family	Common Name	Scientific Name	Duration (days)	Temp (°C)
Scombridae	Atlantic mackerel	*Scomber scombrus*	39.5	15
	Bluefin tuna	*Thunnus thynnus*	27.9	26
	Bullet mackerel	*Auxis rochei*	16.0	25.5
	Frigate mackerel	*Auxis thazard*	9.5	25.5
	King mackerel	*Scomberomorus cavalla*	11.7	28.5
	Little tunny	*Euthynnus alletteratus*	24.4	26
	Pacific chub mackerel	*Scomber japonicus*	17.3	19.5
			21.1	16.8
			14.3	22.1
	Skipjack tuna	*Katsuwonus pelamis*	20.2	26.7
	Southern bluefin tuna	*Thunnus maccoyii*	24.1	27.5
	Spanish mackerel	*Scomberomorus maculatus*	8.6	28.5
	Yellowfin tuna	*Thunnus albacares*	25.1	26.5
Bothidae	Turbot	*Scophthalmus maximus*	39.3	15
Paralichthyidae	Summer flounder	*Paralichthys dentatus*	98.8	18
Pleuronectidae	European plaice	*Pleuronectes platessa platessa*	100.0	4.5
	Winter flounder	*Pseudopleuronectes americanus*	87.0	6
Solidae	Dover sole	*Solea solea*	35.1	18
Achiridae	Lined sole	*Achirus lineatus*	23.0	28

GULF OF MEXICO ASSESSMENT ZONES

For CWIS assessment purposes, the GOM was subdivided into 15 zones (Figure 2). The three major north-south divisions correspond to the three Outer Continental Shelf Continental U.S. Planning Areas (2007-2012): the Western GOM (W), Central GOM (C), and Eastern GOM (E).

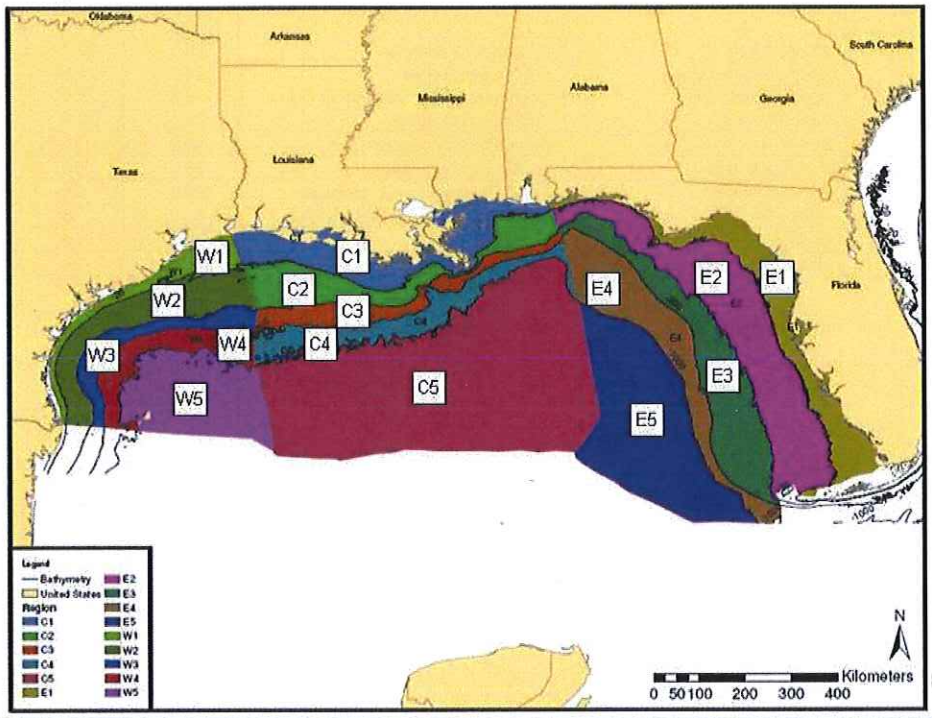


Figure 2. Zones for fishery data and water-use assessment.

Each of the three planning areas is further subdivided into five depth zones. The depth ranges of the zones 1 through 5 correspond, respectively, to 0-20 m, 20-60 m, 60-200 m , and 200-1000 m, and >1000 m. The three shallowest zones represent waters of the continental shelf. The three depth subdivisions are presently used in shrimp trawl bycatch assessments based upon their biological homogeneity. Depth zone 4 covers the continental slope and depth zone 5 deep abyssal waters out to the limit of the EEZ.

LARVAL AND EGG DENSITY DATA SOURCES

Ichthyoplankton

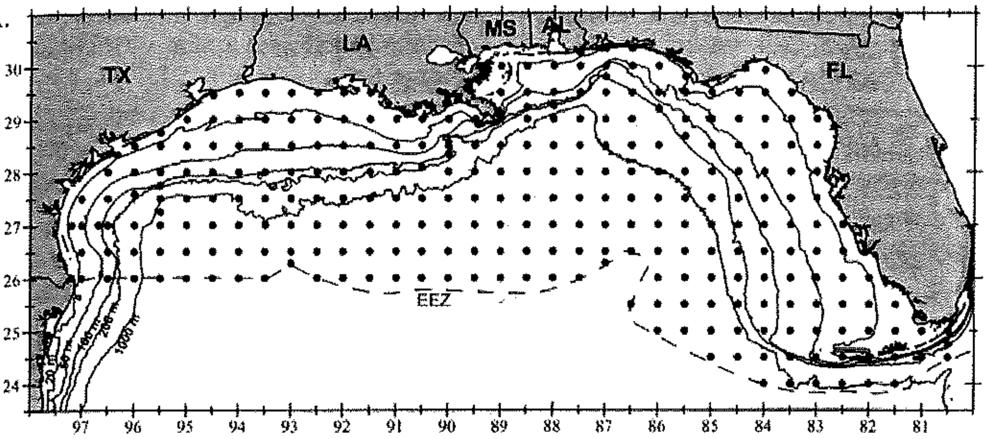
In the early stages of the GOM LNG assessment process, a review of available literature and discussions with NOAA Fisheries identified the Southeast Area Monitoring and Assessment Program (SEAMAP) database as the best representation of existing ichthyoplankton (fish eggs and larvae) conditions in offshore waters of the GOM (e^2M 2005). SEAMAP data became the principal datafile for subsequent LNG assessments in the GOM (USCG and MARAD 2003, 2004, 2005a, 2005b, 2006a, 2006b; TORP 2006).

Ichthyoplankton sampling has been conducted in the GOM as part of SEAMAP since 1982 (Rester et al. 2000). The sampling is conducted at standard stations which are located at 30 mi or ½ degree (~56 km) intervals comprising a fixed, systematic grid across the Gulf (Figure 3, from Lyczkowski-Shultz et al. 2004). Occasionally, samples are taken at non-standard locations or stations are moved to avoid navigational hazards. Samples are taken upon arrival at a station regardless of time of day. Sampling cruises are routinely made during the summer and fall (June-November), but historically there are numerous records for the month of May. July and September are typically the focal months of these surveys.

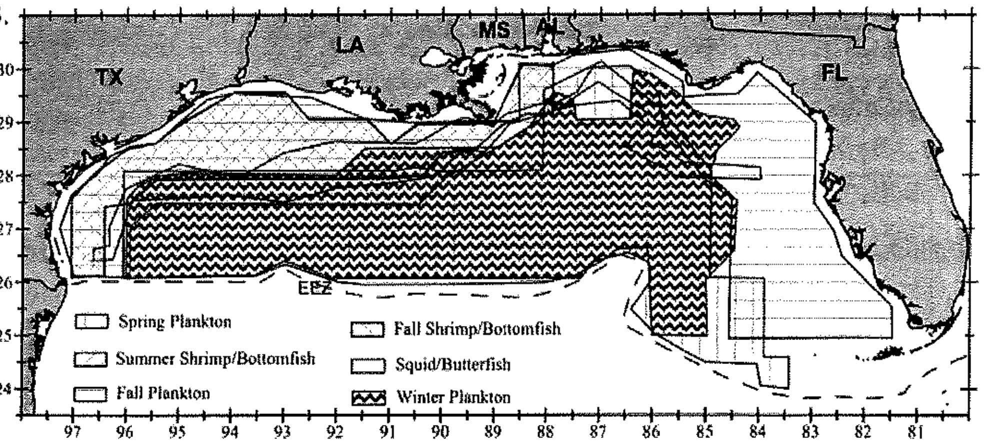
Lyczkowski-Shultz et al. (2004) reported that the sampling gear and methodology used for SEAMAP ichthyoplankton surveys follow Kramer et al. (1972), Smith and Richardson (1977), and Posgay and Marak (1980). A 61-cm bongo net fitted with 0.333-mm mesh is fished in an oblique tow path to a maximum depth of 200 m or to 2- to 5-m off the bottom at depths less than 200 m. A mechanical flow meter is mounted off-center in the mouth of each bongo net to record the volume of water filtered. Volume filtered varies between ~20 to 600 m^3, but is typically 30 to 40 m^3 at the shallowest stations and 300 to 400 m^3 at the deepest stations. These data provide density estimates; i.e., number of larvae or eggs per m^3. In addition to the bongo net sampling, a single or double 2- by 1-m pipe-frame neuston net fitted with 0.947-mm mesh is towed at the surface with the frame half submerged for 10 minutes. These data yield catch-per-unit effort (CPUE) rather than density indices.

Catches from bongo nets are standardized to account for sampling effort (i.e., volume filtered) and then expressed as the number of larvae under 10 m^2 of sea surface (Lyczkowski-Shultz et al. 2004). This is accomplished by dividing the number of larvae of each taxon caught in a sample by the volume of water filtered during the tow, and then multiplying the resultant by the maximum depth of the tow in meters and the factor 10. For our purposes, the density estimate (number/m^3) is the value of interest.

A.



B.



Survey type Number of BN/NN samples	Months	Primary survey area	Time period	% Total BN/NN samples
Winter plankton 332 / 289	Dec Jan, Feb	Coastal LA; Shelf edge to U.S. EEZ	1982–1997; 1983 & 1984, 1993 & 1996	4.7 / 3.6
Spring plankton 2196 / 3209	Mar, Apr, May, Jun	Coastal LA; Shelf edge to U.S. EEZ	1982–1995; 1982 to present	31.1 / 40.3
Summer trawl 1052 / 977	Jun, Jul	5 to 50 fm, south TX to Mobile Bay	1982 to present	14.9 / 12.3
Squid/butterfish 88 / 85	May, Aug	Shelf edge northern Gulf	Aug 1985, May 1986	1.2 / 1.1
Fall plankton 2273 / 2413	Aug, Sep, Oct	Coastal & shelf waters, south TX to south FL	1986 to present	32.2 / 30.3
Fall trawl 867 / 762	Oct, Nov, Dec	5 to 50 fm, south Texas to Mobile Bay	1982 to present	12.3 / 9.6
Other 253 / 221	Mar, Apr–Nov	West of Mississippi River off LA	Mostly pre-1986	3.6 / 2.8

Figure 3. SEAMAP sampling grid (A), seasonal sampling areas by program (B) and distribution of effort. Source: Lyczkowski-Shultz and Hanisko (2007).

Initial processing of SEAMAP plankton samples is carried out at the Sea Fisheries Institute, Plankton Sorting and Identification Center (ZSIOP), in Szczecin, Poland and the Louisiana Department of Wildlife and Fisheries (LDWF) (Lyczkowski-Shultz et al. 2004). Vials of eggs and identified larvae, plankton displacement volumes, total egg counts, and counts and length measurements of identified larvae are sent to the SEAMAP Archive at the Florida Marine Research Institute in St. Petersburg, FL. These data are entered into the SEAMAP database and specimens are curated and loaned to interested scientists. Data files containing specimen identifications and lengths are sent to the NMFS Mississippi Laboratories where these data are combined with field collection data and edited according to established SEAMAP editing routines. SEAMAP survey data are currently maintained in dBase file structures but conversion to an Oracle based system is underway.

There are two important points to note concerning the use of SEAMAP data. First, in assessments of LNG facilities in the GOM, a standard USCG/MARAD protocol is to multiply all reported ichthyoplankton densities by a factor of 3 to account for the extrusion of the smallest larvae though the mesh net (USCG and MARAD 2003, 2004, 2005a, 2005b, 2006a, 2006b). This protocol was adopted to cover the larvae of all species of fish. This report adheres to that precedent. All larval densities obtained from the SEAMAP database are multiplied by a factor of 3 prior to any detailed analysis. Second, SEAMAP data are for the eggs and larvae of fish only and do not include data for invertebrates (e.g., brown shrimp, white shrimp, etc.). Data sources for these invertebrate taxa are described further below.

A detailed description of methods for analyzing the SEAMAP ichthyoplankton data is provided in Appendix A. These descriptions identify the three SEAMAP datasets (STATCARD, ICHSTRWK, ICHSARWK) that are used together to estimate fish larvae and egg densities, and the relevant fields within each dataset. Here, we should also note that the SEAMAP database is more-or-less continually being updated (i.e., adding the next year's results, receipt of new laboratory analysis results from ZSI0P and LDWF, corrections of errors, etc.). Because the SEAMAP files are subject to updating, it is a best practice for any analysis based on this data to state the name and provenance of the datafile that was used. The results in this report use the file named "Ichthyoplankton _09_02_2004_ascii.zip" as provided by David Hanisko, NMFS, Pascagoula Laboratory, Mississippi.

The STATCARD dataset describes when and where sampling operations took place. The ICHSTRWK is the dataset which contains gear code information, volumes filtered and all of the egg data, whereas the ICHSARWK dataset provides data about individual taxa including size information. As described in Appendix A, STATCARD and ICHSTRWK can be merged based upon three fields (cruise number, vessel, Pascagoula Station Number). The sample number field is required to merge these data with the ICHSARWK dataset. Further analytical detail is provided in Appendix A.

Standardization of Data

Calculation of larval and egg densities for each species followed a common protocol. For each species, a critical time frame of exposure was determined from life-history data. For example, red drum spawn in the GOM primarily during the months of September and October. Across all SEAMAP data, 98.3% of all tows containing red drum larvae are collected in September-October. In this case, SEAMAP ichthyoplankton data for these two months of exposure were used to calculate regional larval densities. Density estimates thus focus on the peak spawning period and are not diluted by marginal monthly densities or outliers that may precede or follow the prime spawning season. The duration of entrainment also focuses on the prime spawning season and is not overestimated by the presence of outlying data points (isolated tows containing red drum larvae).

Within each of the 15 zones, the total number of quantitative ichthyoplankton tows was determined for September-October. As addressed above, larval densities for each ichthyoplankton tow are expressed as the number of individuals per m^3 times a factor of 3 to account for extrusion loss. Larval density was then summed across all tows within the zone. This sum was then divided by the total number of tows to yield a mean density estimate $\pm$ 95% Confidence Interval (CI). By convention for this report, the 95% upper CI is denoted as UCL and the 95% lower CI is denoted as UCL. These densities are then used to estimate entrainment loss based upon seawater usage estimates.

Although SEAMAP reports densities of fish eggs, eggs are not identified to any taxonomic level. Estimation of species-specific egg density assumes that the ratio of species-specific egg density to overall egg density is the same as the ratio of species-specific larval density to overall larval density (USCG and MARAD 2003, 2004, 2005a, 2005b, 2006a, 2006b; e^2M 2005; TORP 2006). If red drum larval density constituted 1% of total larval density (all species combined) for any given zone, it is assumed that 1% of egg density for that zone are red drum.

Egg densities by zone and time frame are calculated in the same fashion as described above for larvae to yield a mean egg density estimate for the zone. The ratio of mean red drum larval density to mean total larval density is applied to the mean egg density estimate for the zone to yield the estimated density of red drum larvae. These densities are then used to estimate the entrainment loss of red drum eggs based upon seawater usage estimates.

Invertebrates

As mentioned previously, SEAMAP provides no egg and larvae data for invertebrates. Two sources of larval shrimp and/or crab density data were located, each of which incorporated a monthly sampling regime. The first was a study of planktonic shrimp conducted in 1961 off the upper Texas coast and western Louisiana as reported by Temple and Fischer (1967). The second data source (Sasser and Visser 1998) was from the comprehensive plankton studies conducted by the LDWF for the Louisiana Offshore Oil Port, Inc. (LOOP) project. These data sources were originally used to assess invertebrate egg and larval entrainment at the Pearl Crossing LNG Terminal LLC Project (Gallaway et al. 2005b).

Temple and Fischer (1967)

This larval and postlarval penaeid shrimp study was conducted monthly in 1961 at 11 stations where water depths were 14, 27, 46, and 82 m (Figure 4). One transect consisting of four of these stations was located along a north-south line offshore Cameron, Louisiana. The eastern edge of this study area extended to near the Pearl Crossing LNG terminal site, but most sampling was conducted west of the proposed site.

Plankton samples were obtained with the Gulf-V plankton net described by Arnold (1959). This gear consists of a metal frame to which a conical monel net with a mesh size of 31.5 strands per centimeter (0.317 mm mesh) was attached. The diameter of the net mouth was about 40.5 cm. Plankton was collected in a cup attached to the end of the net. Estimates of water volume filtered during each tow were calculated from a flow meter positioned in the center of the net mouth.

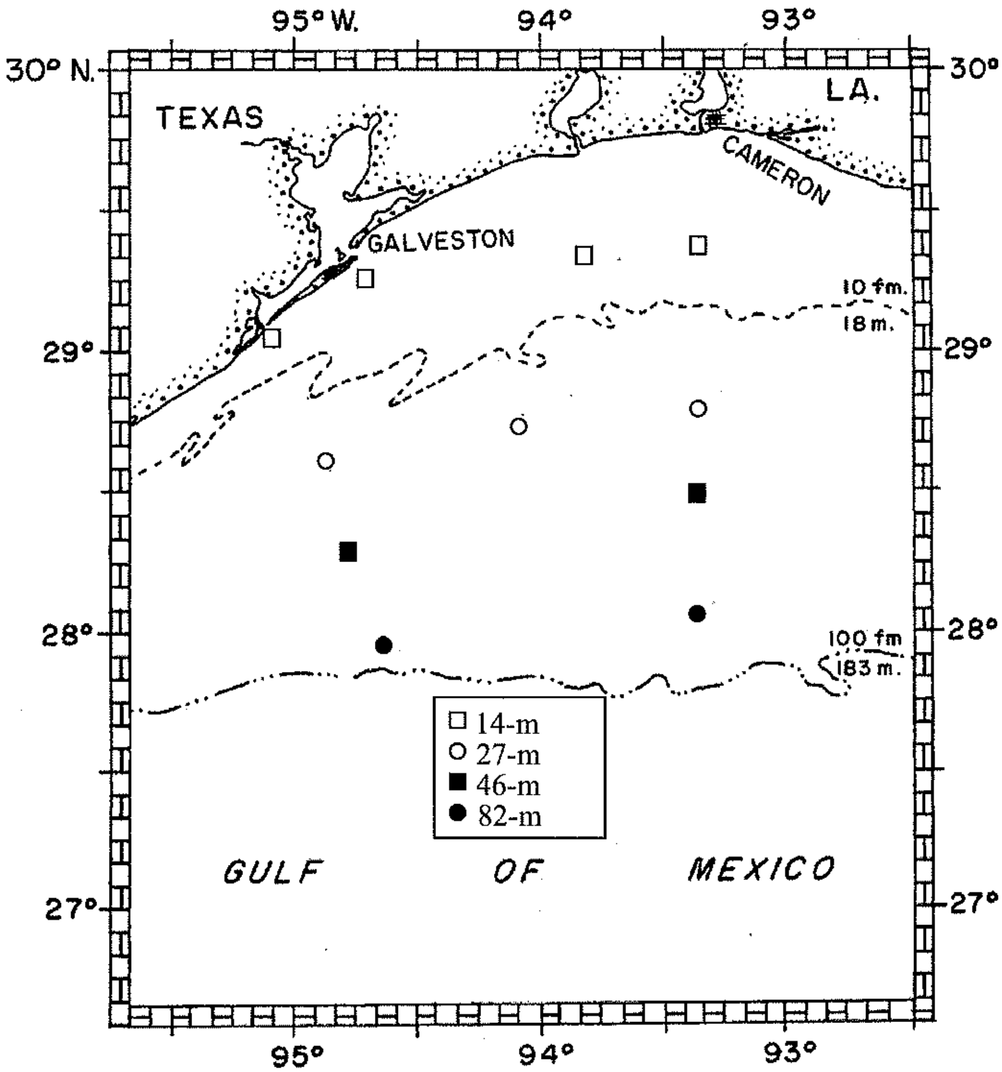


Figure 4. Sampling stations occupied during January-December 1961 as reported by Temple and Fischer (1967).

Each tow lasted 20 minutes, and towing speeds averaged 4.6 km per hour (2.5 knots). Flow meter readings indicated that during each tow the net filtered about 100 m^3 of water. Catches are reported as numbers of organisms per 100 m^3 of water strained. We converted these to numbers/m^3 for our analyses. Each of four depths was fished for 5 minutes during each tow: 3 m above the bottom, two intermediate depths, and 3 m below the surface. The two intermediate depths fished were equally spaced vertically within the water column and depended on the total water depth.

The oblique-step tow used by Temple and Fischer (1967) was an attempt to eliminate possible differences in day and night catches caused by diurnal migrations of larval shrimp. Temple and Fischer (1965) had observed diurnal migrations in planktonic stages of penaeid shrimp in the northwestern GOM when temperature profiles indicted a stratified water column. They conducted a day-night comparison and results of these studies using the sampling protocol showed no significant differences by time of day. They concluded that the oblique-step tow apparently prevented possible differences in day and night catches caused by diurnal migrations of larval shrimp.

Temple and Fischer (1967) were only able to identify larval and postlarval stages to genus *Penaeus* because the taxonomy of the time did not permit species-level identification of the early life stages. However, they suggested that the larval and postlarval density data from the 14-m stations likely represented white shrimp and that the data from deeper stations represented brown shrimp. Given this premise, white shrimp larvae were most abundant in June-August and postlarval were most abundant in August. Minor peaks in white shrimp postlarval abundance were seen in October and February-March.

Brown shrimp larvae were most abundant during September-December with postlarvae being most abundant in October-November. They were scarce or absent during other months of the year.

LDWF LOOP Data.

The LDWF LOOP plankton monitoring data provided to us by LDWF covered the period January 1982-December 1995 and was named LOOP Plankton Data Base, Card Type II (LPDB11). This dataset is somewhat difficult to work with since it uses 80-column data formats developed when punch cards were the only means of data entry. Four sampling gears and six different gear deployment protocols were employed over the duration of the LOOP study which was conducted at one time or another in environments ranging from freshwater to marine habitats on the mid continental shelf. For the most part, sampling was conducted monthly.

The marine portion of the study most appropriate to our assessment was conducted using bongo nets and a ring net. The ring net used a conical plankton net with a 1-m diameter mouth and a mesh size of 0.363 mm. This net was towed horizontally near the surface for 3 to 5 minutes depending upon plankton abundance to prevent net clogging. Sampling using this gear was conducted at nine stations (Figure 5). Other stages of these species were not routinely identified. Brown shrimp postlarvae were most abundant during January-March and December. White shrimp abundance was low as compared to brown shrimp and highest abundance was generally seen in the September-February period depending upon station. Blue crab megalopal larval abundance at Station 704 peaked in March, May and September.

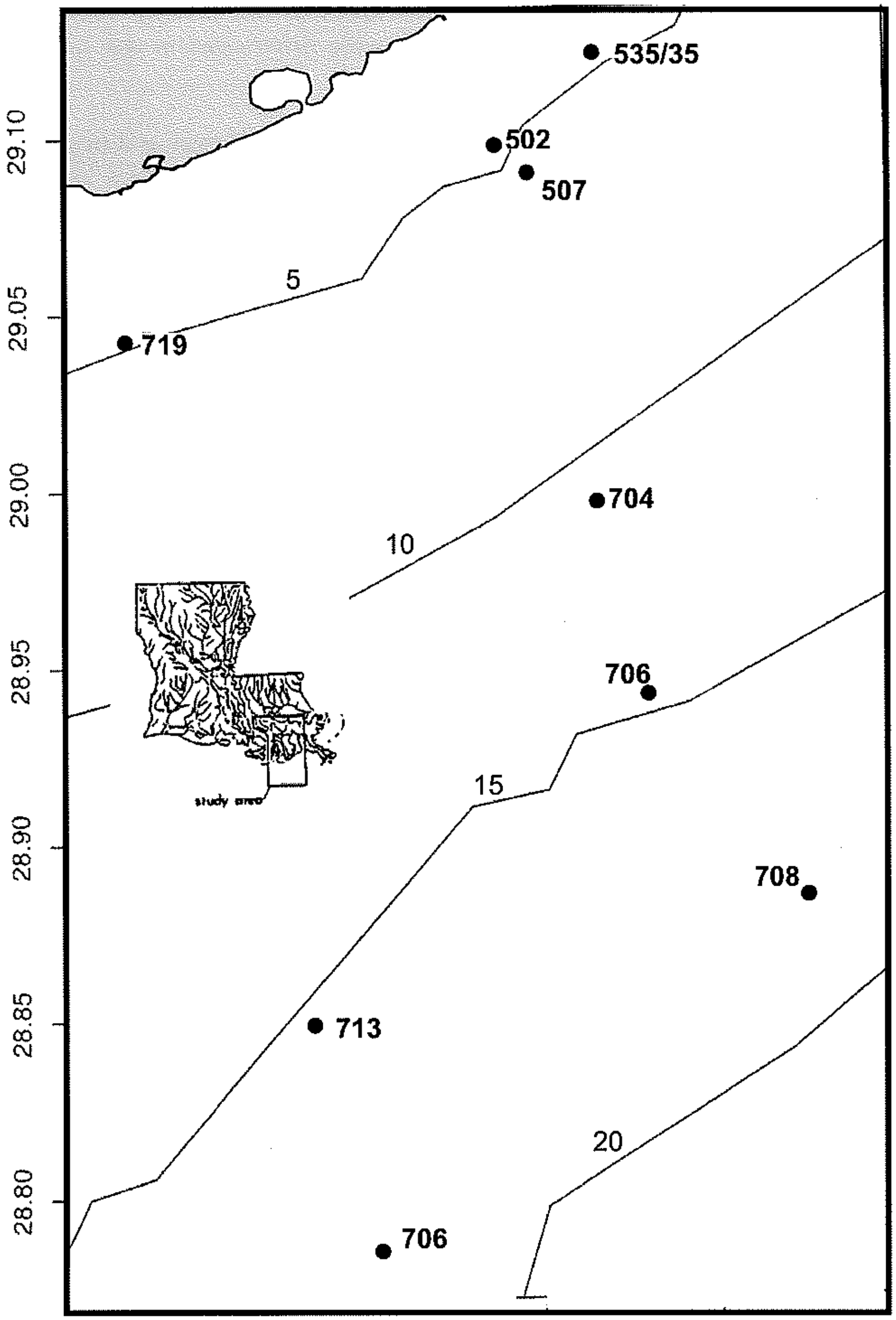


Figure 5. LOOP, Inc. environmental monitoring stations sampled using the 1-m diameter surface-towed, conical plankton net 0.363-mm mesh size. Depth contours are at 5-fathom intervals.

The bongo nets used in the LOOP studies had 60-cm diameter mouths and 0.363 mm mesh nets attached to an opening and closing, paired net frame (Shaw et al. 1998). Bongo nets were towed at 1 m/second (approximately 2 knots) for 3 to 5 minutes, depending upon plankton abundance. All nets were equipped with flow meters. Flowmeter readings were used to calculate volume of water filtered. While four bongo net sampling protocols or methodologies were used in the LOOP studies, one was used only once. The three common bongo net configurations were called Bongo Oblique (BO), Bongo Stratified (BS) and Bongo Half Oblique (BH). The first two were conducted at nearshore stations only, where the stations were arrayed along or clustered around the 5-fathom depth contour. The latter protocol was employed at the deeper stations, including Station 704 which was at a depth of about 12 fathoms.

The nearshore BO protocol sampled the entire water column. The paired net was deployed closed, opened at the surface, lowered in stepped increments to near the bottom and then retrieved smoothly to the surface. The station array sampled, sampling effort, and results of sampling for brown and white shrimp postlarvae and blue crab megalopae are shown in Appendix 2. The nearshore BS protocol involved three bongo frames with double trip mechanisms being simultaneously towed horizontally. They were opened and closed at discrete surface, mid-depth, and near-bottom depths.

We consider the key dataset of the LDWF LOOP study for analysis to be the BH results. This protocol involved two sets of bongo net frames and double trip mechanisms which were used to simultaneously sample the upper and lower portions of the water column in an oblique fashion from mid-depth to the surface, and from one meter off the bottom to mid-depth. The net frames were deployed closed, opened at depth (surface and mid-depth), stepped down in increments to mid-depth and near bottom, retrieved to their starting depths, and closed. The stations sampled using this protocol included 704, 706, 708, 711, and 713 (see Figure 5).

More detailed profiles of the LOOP datafile is addressed on an individual taxon basis in the Species Profiles section in Appendix D.

HIERARCHICAL DATA

SEAMAP ichthyoplankton data are often limited in the level of taxonomic identification that can be achieved. For some species, identification to the species level may not be possible. Some of the characteristics that distinguish individual species (e.g., myomere count, vertebrate count, fin ray count) may not become evident until the later stages of larval development. The researcher may only be able to identify the specimen down to the level of family, or even order. Highly detailed taxonomic identification may also be beyond the scope of a particular work. Studies that specifically focus on one or a few target species may provide only higher level taxonomic identification for secondary specimens.

As a result of these limitations, there are some data sets in which density data for individual species may be embedded into higher-level taxa. With SEAMAP data, not all larvae can be identified to species. Some larvae are only identified to order, family, genus, or simply as unidentified fish larvae. Nevertheless, the density of the species in question includes some fraction of these higher-level taxa. The representative density of the species within each higher taxa can be estimated in a top-down fashion. As an example, we describe below the initial steps in the procedure used to assess entrainment loss of red snapper at the Bienville Offshore Energy Terminal (BOET) from Gallaway and Fechhelm (2007). Corrections of density for organisms embedded in the counts of higher-level taxa can be significant, as illustrated by the example analysis discussed below, wherein only 15% of the density of red snapper larvae is due to individuals identified directly as red snapper.

Within the SEAMAP database for the BOET, there were five different identified taxonomic levels that could contain red snapper: *Lutjanus campechanus*, *Lutjanus* sp., Lutjanidae, Perciformes, and Unidentified Fish. Red snapper (*L. campechanus*) belong to the genus *Lutjanus*, which belongs to the family Lutjanidae, which belongs to the order Perciformes, which is contained in the group Unidentified Fish (Figure 6). Based upon SEAMAP ichthyoplankton survey data, the average density of total larval fish was 2.40115 larvae/ m^3 and the density of unidentified larvae was 0.07547 larvae/m^3 (Table 10). By subtraction, the density of identified larvae was 2.32569 larvae/ m^3. Table 10 also lists the recorded density of the four taxa that could contain red snapper, including *L. campechanus* itself. Table 10 also lists the proportionate contribution of each taxa to total identified fish. Thus, the density of *L. campechanus* (0.0002 larvae/ m^3) divided by the total density of identified fish (2.32568 larvae/ m^3) represents the fraction of identified fish that are red snapper (0.00009). It is assumed that the fractional representation of *L. campechanus* in Identified Fish is the same for the category Unidentified Fish (0.07547 larvae/ m^3). Multiplying the fraction of *L. campechanus* in Identified Fish times the density of Unidentified Fish yields the estimated density of *L. campechanus* contained within Unidentified Fish (0.00001 larvae/ m^3). The same calculations are performed on the other three taxa.

The same apportionments are then calculated for the taxon Perciformes (Table 11). There were a total of 114 taxa identified that are contained in the order Perciformes. The total average density of these 114 taxa was 0.49799 larvae/ m^3. The densities of the three remaining lutjanid taxa are divided by the total to yield the fractional contribution of each. These same proportions are then prorated to the taxon merely identified in SEAMAP as Perciformes to estimate the actual larval densities. But at this point there are actually two measures of Perciformes density: (1) the direct measure from the SEAMAP data (0.00854 larvae/ m^3), and (2) the density of Perciformes estimated to exist with the category Unidentified Fish (0.00028 larvae/ m^3, from Table 2). They cumulatively yield a density of 0.00882 larvae/ m^3. This is the density to which the lutjanid proportions are prorated to yield the density of each contained within the taxon Perciformes.

Table 10. Larval densities of red snapper and higher lutjanid taxa including densities derived from the category "Unidentified Fish".

Taxon	Density (no. /m^3)	Fraction of Identified Fish Larvae	Density within Unidentified Fish Larvae (no./m^3)
Total Fish Larvae	2.40115		
Unidentified Fish Larvae	0.07547		
Identified Fish Larvae=Total - Unidentified	2.32568		
Lutjanus campechanus	0.0002	0.00009	0.00001
Perciformes	0.00854	0.00367	0.00028
Lutjanidae	0.00446	0.00192	0.00014
Lutjanus sp.	0.00057	0.00025	0.00002

Table 11. Larval densities of red snapper and higher lutjanid taxa including densities derived from the category "Unidentified Perciformes".

Taxon	Density (no. /m^3)	Fraction of All 114 Identified Fish Larvae	Density of Red Snapper within Unidentified Fish Larvae (no./m^3)
All 114 Identified Perciformes taxa	0.49799	-	-
-		-	-
Unidentified Perciformes	0.00854	-	-
Unidentified Perciformes from Unidentified Fish (Table 2)	0.00028	-	-
Total Unidentified Perciformes	0.00882	-	-
-	-	-	-
Lutjanus campechanus	0.0002	0.00040	0.00000
Lutjanidae	0.00446	0.00896	0.00008
Lutjanus sp.	0.00057	0.00114	0.00001

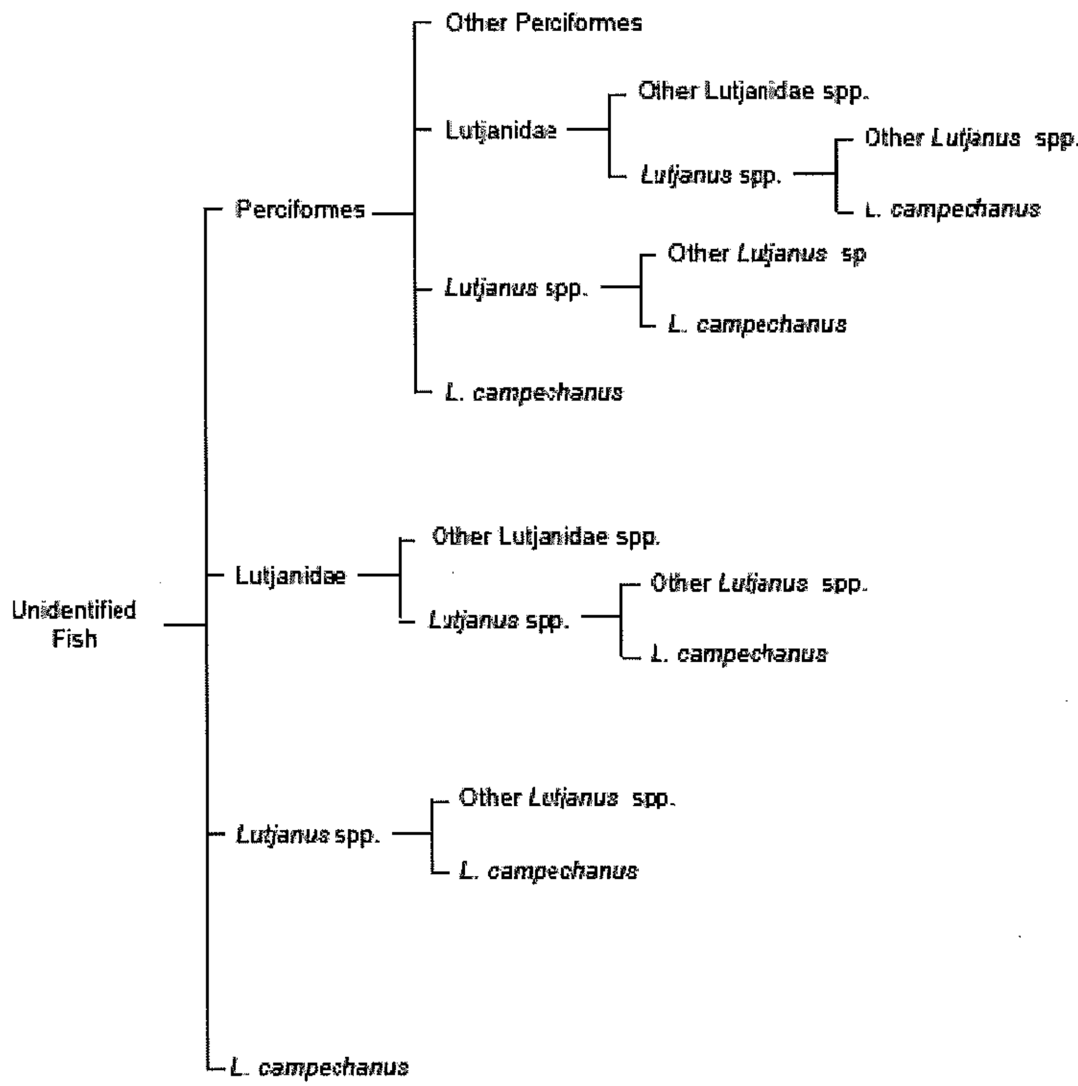


Figure 6. Hierarchy of taxa in the category Unidentified Fish that could contain red snapper *(L. campechanus)* larvae for SEAMAP data used to assess entrainment losses at the Bienville Offshore Energy Terminal (BOET).

This process is applied iteratively in top-down fashion until the density of *L. campechanus* is derived for all four higher level taxa. Note that when prorating for the next level (the family Lutjanidae) there are three sources of density to consider: 1) the direct density of Lutjanidae measured from the SEAMAP data, 2) the density of Lutjanidae estimated to exist with the category Perciformes (see Figure 6), and 3) the density of Lutjanidae estimated to exist with the category Unidentified Fish (see Figure 6).

For the BOET assessment, the total density of *L. campechanus* was estimated to be 0.00133 larvae/ m^3. This was the density used to estimate annual entrainment loss at the facility. Of interest, only 15.1% of the red snapper density was attributable to the actual identification of *L. campechanus* in the SEAMAP data. Of the total density, *Lutjanus* sp. accounted for 67.2%, Lutjanidae for 17.0%, Perciformes for 0.3%, and Unidentified Fish for 0.5%.

This hierarchical adjustment to SEAMAP densities is performed for every taxon quantitatively addressed in this report.

SPECIES DISTRIBUTION MAPS

In conjunction with the CWIS assessment, species distribution maps were compiled to identify areas of high abundance in the GOM for selected species of fish and shellfish. Distribution maps were compiled from two independent sources: (1) the Gulf of Mexico Coastal and Ocean Zones Strategic Assessment: Data Atlas (NOAA 1985), and (2) the Southeast Area Monitoring and Assessment Program (SEAMAP). Species distribution maps prepared for various purposes can provide qualitative indications of the presence or absence of certain species in the various assessment zones.

Gulf of Mexico Coastal and Ocean Zones Strategic Assessment: Data Atlas

Species distribution maps for selected finfish and shellfish were compiled by the NOAA, National Ocean Service, and the NMFS Southeast Fisheries Center, which was published as NOAA (1985). These maps were compiled from the existing scientific literature and are still considered the standard reference source for the GOM. The atlas contains distribution maps for 15 invertebrate and 47 finfish species for the GOM. These maps were obtained in two ways. Some of the maps were digitally scanned into Geographic Information System (GIS) digital formats and electronically digitized into GIS files (i.e. shapefiles). Others were downloaded from the NOAA satellite and information service website (http://www.ncddc.noaa.gov/ interactivemaps/gulf-of-mexico-coastal-habitat) in GIS file format (shapefiles) and imported into a GIS.

A representative distribution map for brown shrimp is presented in Figure 7.

SEAMAP

Details of the SEAMAP ichthyoplankton sampling survey are provided in previous sections. An additional component of SEAMAP includes summer and fall shrimp/groundfish surveys (see Figure 3).

Spatial estimates of the abundance of finfish and shellfish having a benthic life stage over soft bottom habitat can be estimated from the summer fall groundfish SEAMAP surveys. Nichols and Pellegrin (1989) provide the details of the sampling program history for these data. In brief, this time series began in 1972 as the "Fall Groundfish Survey" and concentrated on the north-central region of the Gulf. The "primary survey area" was 5 to 50 fm waters between 88° and 91°30'W. During some years, spring and summer samples were also taken. The goal was to obtain triplicate tows of 10-min duration at "stations", which were randomly-selected 2.5 minute latitude-longitude grids within a 10-minute block that had been randomly selected from a list of all blocks. The station selection procedure was changed in 1978 but random selection of stations remained the keystone of the sampling plan. In 1985 and 1986, single 15-minute tows were taken at each site, and the program was expanded geographically with the intention of covering the region from Pensacola, Florida, to Brownsville, Texas. In 1987, the SEAMAP procedure, as described below, was adopted and continues to present. The region sampled extends from Pensacola to Brownsville.

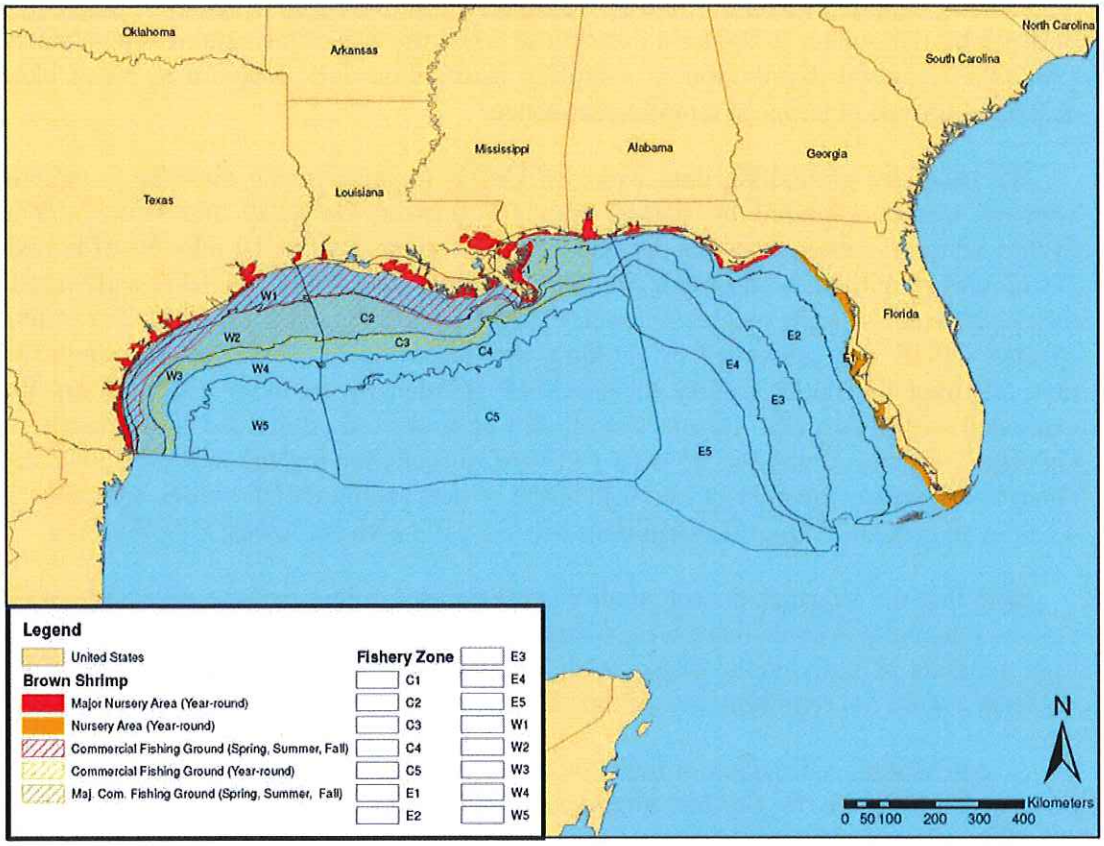


Figure 7. NOAA distribution map for brown shrimp in the GOM. Source: Gulf of Mexico Coastal and Ocean Zones Strategic Assessment: Data Atlas (NOAA 1985).

Fall sampling has generally been restricted to October to November of each year. In the early years, sampling proceeded from east to west, so that missed samples were more frequent in the western part of the region sampled than the eastern part. Since 1987, fall sampling generally begins in mid-October in Statistical Zones 10 and 11, then shifts to Brownsville (Zone 2) and proceeds back towards Pensacola. Typically, by the end of October sampling has reached the Galveston/Sabine region. The upper Texas coast and western-Louisiana are mainly sampled during the first 10 days of November, and sampling through the entire primary region occurs during 11-20 November. While the entire western Gulf is sampled within about a 1-mo period, temporal variation may cloud spatial differences.

NMFS has participated in and coordinated federal, state, and university summer sampling efforts since 1982 as part of the Summer SEAMAP program (Goodyear 1995). The trawl sampling gear are the same as used in the Fall Groundfish Survey (Nichols and Pellegrin 1989). The survey covers the area between Pensacola and Brownsville, 5 to 60 fathoms. Stations are selected in a stratified random design, with strata established alongshore (based on commercial shrimp statistical areas), and by depth. Trawling is conducted perpendicular to the depth contours. Duration of each trawl is set by the distance between the inner and outer depth boundary for each stratum. A station begins at the intersection of a depth contour and a randomly chosen alongshore location. Measurement of depth by fathometer in the field determines when the end of the station is reached. Since 1987, the temporal distribution of sampling in the June-July program is much like that described for fall in terms of sampling sequence.

We used the groundfish data from SEAMAP to index mean abundance patterns of selected species captured by bottom trawl. Following Gallaway and Cole (1997) the SEAMAP trawl survey area was divided into cells encompassing 10-minutes of latitude by 10-minutes longitude. Mean catch per hour trawling with a standard 40-ft wide trawl was then calculated for each species for each of the 468 final model cell blocks. For individual species, CPUE was calculated by dividing the total number of individuals caught within that cell over the entire history of SEAMAP divided by the total effort (hours fished) expended within that cell. Results for all 468 cells were then divided into quartile ranks. Quartile 1 represents the top 25% (n =117) of all cells having the highest CPUE values. Quartile 2 contains the next 117 cells in terms of descending CPUE values. Quartiles 3 and 4 follow in sequence. Quartile 4 contains the 117 cells with the lowest CPUE values.

Note that the quartiles do not subdivide the dataset in terms of the full range of CPUE values. For many species there were a small number of trawls that caught extraordinarily high numbers of individuals. These small number of trawls expanded the range of CPUE values but were not representative of the "norm".

A representative distribution map for brown shrimp based upon SEAMAP surveys is presented in Figure 8. Further analytical detail concerning the SEAMAP datafile is provided in Appendix B.

Data Atlas (NOAA 1985) contains distribution maps for 15 invertebrate and 47 finfish species for the GOM. Distribution maps based upon SEAMAP trawl data are available for any demersal species in the GOM for which there is data. However, within this report distribution maps are only used when they contribute to the discussion and CWIS assessment for specific species. While LGL has the capability to produce maps for any species for which there is data (either NOAA [1985] or SEAMAP derived), the vast majority of these maps are not presented in this document. They would be available should CWIS predictions change in the future.

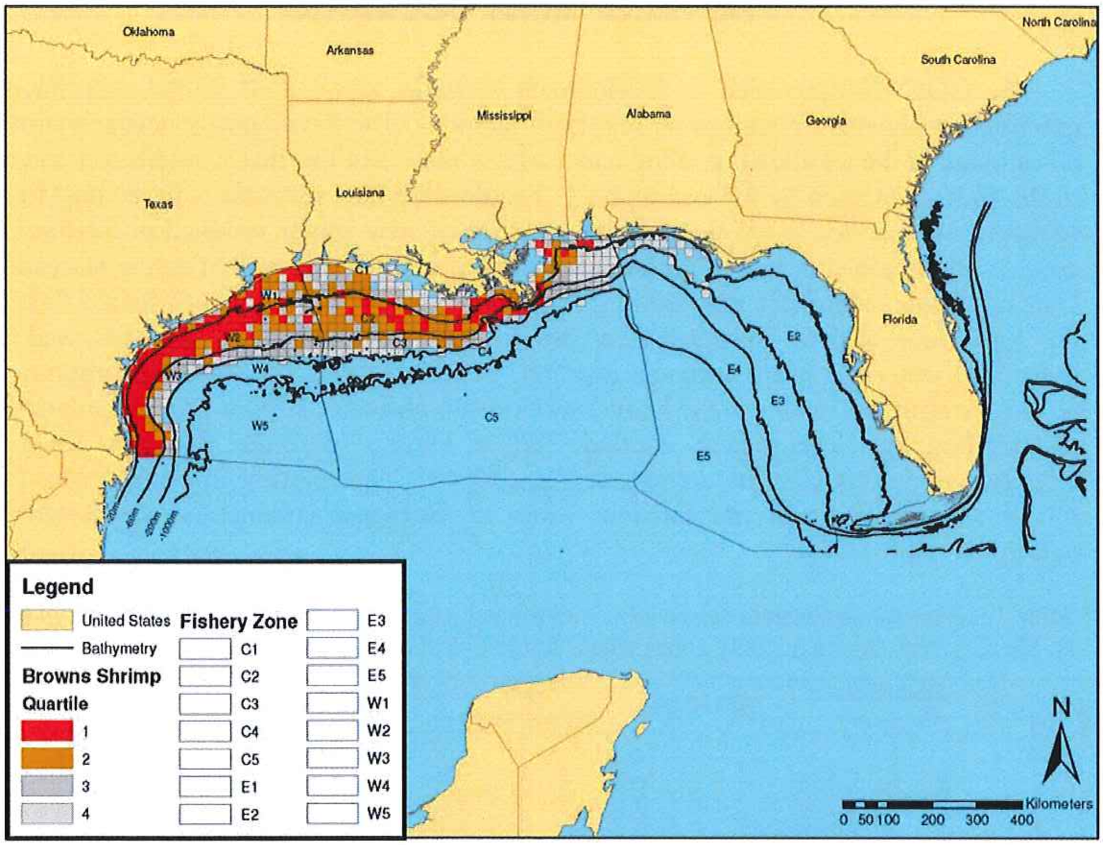


Figure 8. SEAMAP distribution map for brown shrimp in the GOM. Compiled from the SEAMAP demersal trawl datafile. The 15 assessment zones for this report are superimposed.

DEVELOPMENT SCENARIO

The OOC-ESS provided a development scenario to be used in the assessment of entrainment impacts by intakes on regulated facilities. The development scenario provides an estimate of the additional cooling water use by new facilities that would begin operation in the Gulf of Mexico by the end of 2011. The development scenario is based on Minerals Management Service predictions of the number of new major production facilities that come on line each year and a Rigzone.com analysis of the locations of active leases in the Gulf of Mexico and of the new drilling rigs expected to join the Gulf of Mexico fleet over the same time period. Expected new drilling rigs and production facilities, and their associated water use, were assigned locations in fishery zones based on the proportion of active leases in that zone and the known water depth characteristics of production platforms and drilling rigs. This report, entitled *Gulf of Mexico Newbuild Rigs and Fleet Size Changes*, is presented in its entirety as Appendix C. The relevant information on future CWIS seawater usage is presented in Table 12. Seawater volumes are converted from gallons to cubic meters.

Table 12. Base case seawater use scenario – additional water use 2009-2011. (Appendix C, Table 1). Shaded areas denote the only zones where future CWIS activity is projected.

Fishery Zone	Production Facilities		Drill Ships		Semi submersibles		Jackups		Total		
	Number	Total Water Usage (MGD)	Number	Total Water Usage (MGD)	Number	Total Water Usage (MGD)	Number	Total Water Usage (MGD)	Daily Water Usage (MGD)	Water Usage Million Cubic	Water Usage Million Cubic
E1	0	0	0	0	0	0	0	0	0	0	0
E2	0	0	0	0	0	0	0	0	0	0	0
E3	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0	0	0
C3	0	0	0	0	0	0	0	0	0	0	0
C4	2	7	0	0	1	8	0	0	15	0.05678	20.73
C5	5	55	5	180	1	8	0	0	243	0.91986	335.75
W1	0	0	0	0	0	0	0	0	0	0	0
W2	0	0	0	0	0	0	0	0	0	0	0
W3	0	0	0	0	0	0	0	0	0	0	0
W4	1	4	0	0	0	0	0	0	4	0.01514	5.53
W5	1	11	1	36	0	0	0	0	47	0.17791	64.94
Total	9	77	6	216	2	16	0	0	309	1.16969	426.94

There are no future CWIS facilities planned for the Eastern Planning Area (Zones E1-E5), the three shallow water areas of the Central Planning Area (Zones C1-C3), and the three shallow water areas of the Western Planning Area (Zones W1-W3).

The smallest non-zero seawater usage by new facilities is projected for Zone W4, in which a single production facility will be placed using 5.53 million m^3/yr. The largest water use is projected for Zone C5 and includes five production facilities, five drill ships, and one semi-submersible for a cumulative seawater withdrawal rate of 335.75 million m^3 per year. Two production facilities and one semi-submersible are projected for Zone C4 (20.73 million m^3 per year), and one facility and one semi-submersible are projected for Zone W5 (64.94 million m^3 per year). Total CWIS usage by new facilities in the entire GOM is projected at 426.94 million m^3 per year.

SPECIES PROFILES AND ENTRAINMENT IMPACT ASSESSMENTS

This section summarizes the fishery information collected on Gulf of Mexico species for this Source Water Biological Baseline Study and the results of entrainment impact assessments for selected species.

The selection of species for discussion in this section was based upon a top-down prioritization of those taxa that are the principal components of the GOM commercial and recreational fisheries. Recognition of the commercial or recreational importance of a species by no means precludes it also occupying a position of ecological importance. At a minimum, these species are also of ecological importance in that they provide a key ecosystem service to the human component of coastal communities. Additional data address a species [I think there is only one] that is considered to be a key forage fish in the Gulf. Although this species is not a target of commercial or recreational fishing, it has ecological importance as a food source for other species.

This section is organized into separate discussions of each of the key species considered. These discussions, or species accounts, provide a summary of biology and fishery information for the species of interest (FFWCC 2009). Species accounts include available information on the commercial or ecological importance of the species, its geographic distribution, spawning behavior and fecundity of the species, and life history information used to model the impacts of entrainment on fishery populations. Together with a development scenario that gives a predicted cooling water use by new facilities, this information provides the based for assessing the impact of CWIS on fisheries.

Considerable life-history information has been compiled for certain species which renders them prime candidates for the assessment of CWIS entrainment impacts. The most extensive data are available for the most important species. These are species such as red snapper and red drum, each of which has been the focus of intense stock assessment analysis in the GOM for a number of years. For other species very little life-history data has been compiled and assessment of entrainment impacts is virtually impossible at this stage.

The development of the full set of fishery information needed for a comprehensive assessment of a species takes place over years or even decades of research and analysis. It should be recognized that the available data suffer from some limitations even for the most carefully studied species. However, fishery management analyses and decisions have traditionally moved forward based on the use of the best information available at the time (Walker and Fletcher, 1996).

A significant effort was made to comprehensively survey the available fishery information for all regions of the Gulf of Mexico. Much background data are presented for certain species and regional larval and egg density estimates were compiled. For some key species, no development is planned to occur in their spawning grounds and thus no assessment of larval and egg entrainment loss is needed. Nevertheless, full biological backgrounds are presented, and egg and larval density information obtained, for each species for which that information exists. This discussion is intended to provide a means of accessing the full extent of information in the scientific literature on the species of interest. This information will be of use in the event that new areas of the Gulf of Mexico become attractive for future development. Using the framework developed in this report, an experienced fishery analysis could update density information from the most recent SEAMAP datasets to develop an entrainment impact assessment comparable to those presented in detail in this report.

Life history data provide the means for predicting the impacts of entrainment losses of egg and larvae on the numbers of adult fish of a given age or the numbers of additional eggs that would be needed to compensate for entrainment losses. The use of life history data in impact assessment is discussed in detail in studies such as Gallaway et al (2007) and e^2M (2005). The following explanation provides the basic background needed to understand how life history data are used in entrainment assessment.

Life history data provide the duration and probability of mortality of each life stage of an organism. Fish typically begin life as fertilized eggs which then hatch into larvae. The larvae develop through a progression of juvenile life stages before becoming adult organisms. Egg, larval, and juvenile life stages each have a duration d (units of days) and an instantaneous mortality rate M (units of day^{-1}) such that the fraction of organisms surviving a given stage is e^{-dM}. The product dM is referred to as the stage mortality which is dimensionless. The stage mortalities of successive stages combine additively.

The reproductive strategy of fish is to produce very large numbers of eggs to compensate for the high natural mortality of both the eggs and the subsequent larval life stages. Due to the high mortality of fish eggs and larvae, the fraction of eggs surviving to age one year is typically (based on base case example in e^2M, 2005) very small, e.g. 0.01 – 0.02%. As a result, entrainment of even large numbers (tens or even hundreds of millions) of eggs or larvae typically leads to losses of older fish that are insignificant compared with those due to natural mortality or to other anthropogenic stresses such as fishing.

Brown Shrimp (*Farfantepenaeus aztecus*) (Rank 1: Commercial Fishery)

The brown shrimp is a benthic- and estuarine-dependent invertebrate found from the shore to depths of 110 m but is mostly abundant between 30 and 55 m (Figure 9, NOAA 1985). Brown shrimp spawn primarily in waters deeper than 14 m (Renfro and Brusher 1982). At depths of about 27 m, the period of greatest spawning activity is in September with a smaller peak in May; at 46 m peak spawning activity is in October-December with a smaller peak from March-May; and, at deeper depths spawning occurs throughout the year (Cook and Lindner 1970).

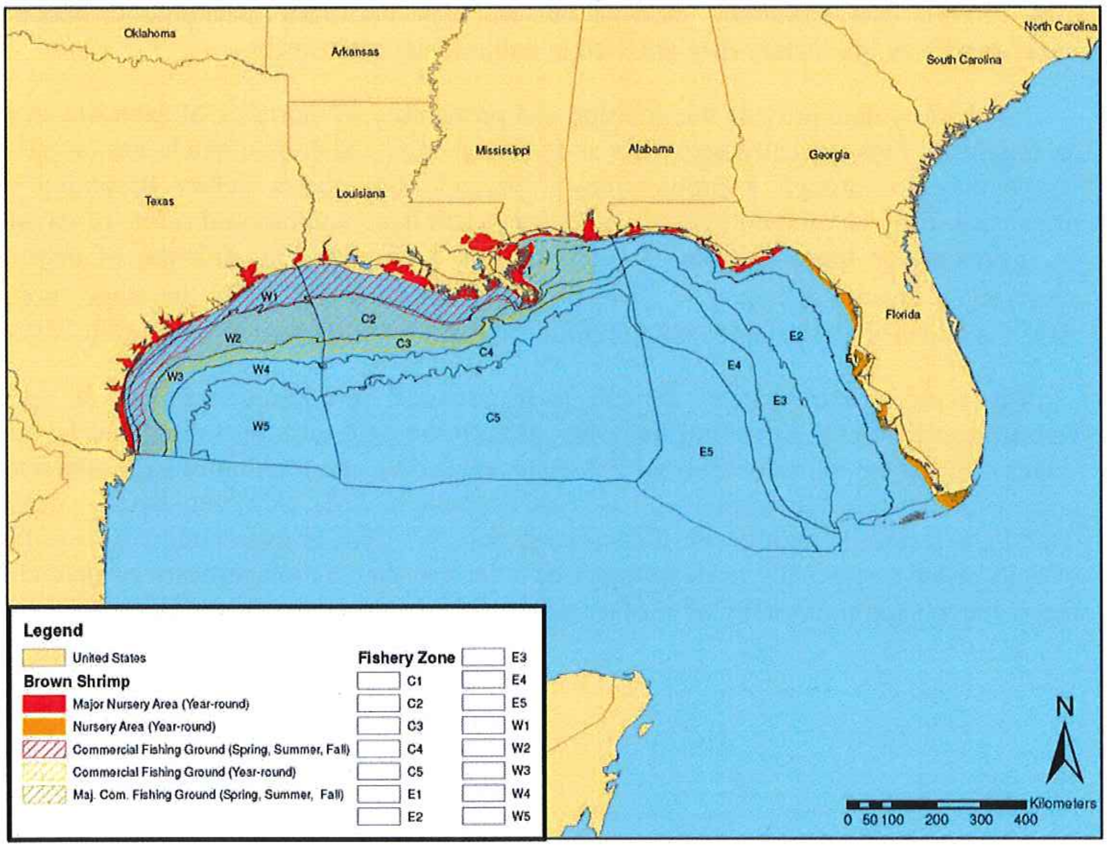


Figure 9. Distribution of the brown shrimp in the GOM. Source: NOAA (1985).

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because the reproductive activities of brown shrimp are associated with shelf, shallow nearshore, and estuarine waters of the Gulf inside the 60 m isobath, CWIS impacts is not an issue for this species.

Life-History Background

Although no CWIS facilities are planned for brown shrimp spawning areas of the Gulf, considerable life-history information has been compiled for this species including the necessary egg and larval mortality and duration estimate needed for an entrainment loss assessment. Life history data for entrainment assessments are presented below. Assessment life-history summaries are presented in Appendix Table D1.

Larval studies conducted monthly in 1961 reflected that peak spawning likely occurred in September-November (Temple and Fischer 1967). Estimates of fecundity range from 246,000 eggs per female (Reitsema et al. 1982) to as many as 500,000 to 1,000,000 eggs per female (Wallace 1997).

In studies of wild Penaeid populations, *F. aztecus* larvae are most commonly sampled below mid-depth (SMS 2005). Protozoea of this species are likely to occur nearest the bottom, while postlarval stages occur at, or slightly above mid-depth. However, all stages ascend to surface waters with the onset of darkness (SMS 2005).

Lassuy (1983a) and references therein report that the larvae pass through 5 naupliar, 3 protozoeal and 3 mysis stages over a 10- to 25-day period before transforming into postlarvae. Cook and Murphy (1966) conducted laboratory experiments in which 219 of 1,200 naupliar larvae survived to the last mysis stage within a 13-day period.

Peak recruitment of postlarvae into the estuaries of the northern GOM appears to occur months after the peak in spawning (Lassuy 1983a). For example, Baxter and Sullivan (1986) report that peak movement into Galveston Bay occurred in March and April. Minello et al. (1989) in a mortality study of young brown shrimp in Galveston Bay reported the first cohorts moved into the marsh in late March or early April.

These observations suggest that, for brown shrimp, the early oceanic postlarvae stage may extend over the fall to winter period. Temple and Fischer (1967) suggested that during the winter, brown shrimp may burrow into the bottom and await the advent of warmer temperatures before entering the estuaries. Aldrich et al. (1968) provided laboratory evidence of this behavior; i.e., brown shrimp postlarvae burrowed into the bottom when temperatures were lowered to between 12 to 17° C. St. Amant et al. (1966) reported that brown shrimp postlarvae overwinter in a state of reduced activity when temperatures are low.

If young brown shrimp do overwinter offshore where water temperatures are colder, the developmental rate and growth of the postlarvae would be greatly reduced. Cook and Murphy (1966) observed retarded developmental rates at temperatures lower than 30° C; Zein-Eldin and Aldrich (1965) found that growth of postlarvae held over a 30-day period at 11° C was practically nil, but survival was high.

Bottom water temperatures in the northwestern GOM range between as low as 12 to 17° C between the fall peak in spawning and the spring peak in immigration of postlarvae into the estuary. Based upon the evidence, we believe that the postlarval stage of brown shrimp extends from fall to spring. We use a total early postlarvae stage mortality of M = 1.7 following EPA (2002) citing Costello and Allan (1970).

Rogers et al. (1993) have observed that brown shrimp postlarvae either actively or passively aggregate as they move across the shelf towards the mainland shores and into inshore estuaries. In their surveys, densities of postlarvae were nearly an order of magnitude higher at the shallowest depth-group of stations than at the offshore-depth group of stations. Further, the peak density of postlarvae in the inshore marsh was an order of magnitude higher than in the nearshore marine zone. This trend of increasing densities from offshore spawning grounds to estuarine nursery areas was considered even more significant given the time required to traverse this area and the substantial negative impact of mortality during transport. They provided a behaviorally-mediated transport hypothesis that provides a reasonable explanation of the increasing degree of aggregation of postlarvae as they move from offshore into the inshore estuaries.

The late postlarvae/early juvenile stage of brown shrimp occurs in estuarine habitats. Minello et al. (1989) conducted mortality studies of this stage in Galveston Bay in 1982 and 1987. They observed four separate cohorts, and based upon their data, daily mortality rate ranged from $M = 0.0234\ d^{-1}$ to $M = 0.0554\ d^{-1}$ with an average of $M = 0.0320\ d^{-1}$. The stage is estimated to occur over an approximate 61 days with the estimated range between 47 and 72 days. This stage essentially occurs over the months of April and May. Upon completion of this stage the shrimp are about 70- to 80-mm long and move from marsh edge and other vegetated habitats onto the soft bottoms of open water areas.

Shrimp continue to grow rapidly after moving to open water where they are subject to both fishing and natural mortality. When they have attained sizes of about 90 to 110 mm they emigrate from estuaries to the Gulf. This may occur during May-August, but June and July is often cited as the peak months of emigration (Lassuy 1983a and references therein). They migrate across the nearshore zone to deeper water. By August and September a relatively high proportion of the population in waters 27- to 46-m deep have attained a length of 140 mm or larger, the threshold size for spawning. Renfro and Brusher (1982) reported peak abundance at 46-m depths in September/November.

Subadult/adult natural mortality rates for brown and white shrimp have been estimated to be M = 0.275 per month or $M = 0.0092\ d^{-1}$ (e.g., Nance 1999). This value represents the mid-point of an estimated range of M that falls between 0.2 and 0.35 per month as described by Nance et al. (1989). The base, low, and high estimates of subadult/adult stage duration were simply the balance of the first year given the durations of the preceding life stages.

Gazey et al. (1982a, b) reported natural and fishing mortality estimates for adult brown shrimp based upon a series of mark-recapture studies. The average instantaneous daily natural mortality rate was $M = 0.0256\ d^{-1}$ (95% CI was 0.0126 to 0.0387 d^{-1}). The corresponding average fishing mortality was F = 0.0279 (0.0121 to 0.0436). We used F to M ratios from Gazey et al. (1982a, b) as a multiplier applied to M to obtain an estimate of fishing mortality or F. For example, total subadult/adult M for brown shrimp was 1.2788 and the F:M ratio was 1.09. This yields a corresponding estimate of F = 1.3939.

White Shrimp (*Litopenaeus setiferus*)
(Rank 2: Commercial Fishery)

The white shrimp is found in the coastal water of the GOM from Apalachee Bay, Florida, to northeast Campeche Bay, Mexico (Figure 10, NOAA 1985). They are scarce to absent along the west coast of Florida south of Apalachee Bay. The white shrimp is the second most important species taken in the GOM shrimp fishery with annual landings averaging 101 million pounds worth approximately $178 million (NMFS 2008a). In terms of dollar value, white shrimp account for 24.8% of the entire GOM commercial fishery all species combined. Together, white and brown shrimp account for over 53% dollar value of the entire GOM commercial fishery all species combined.

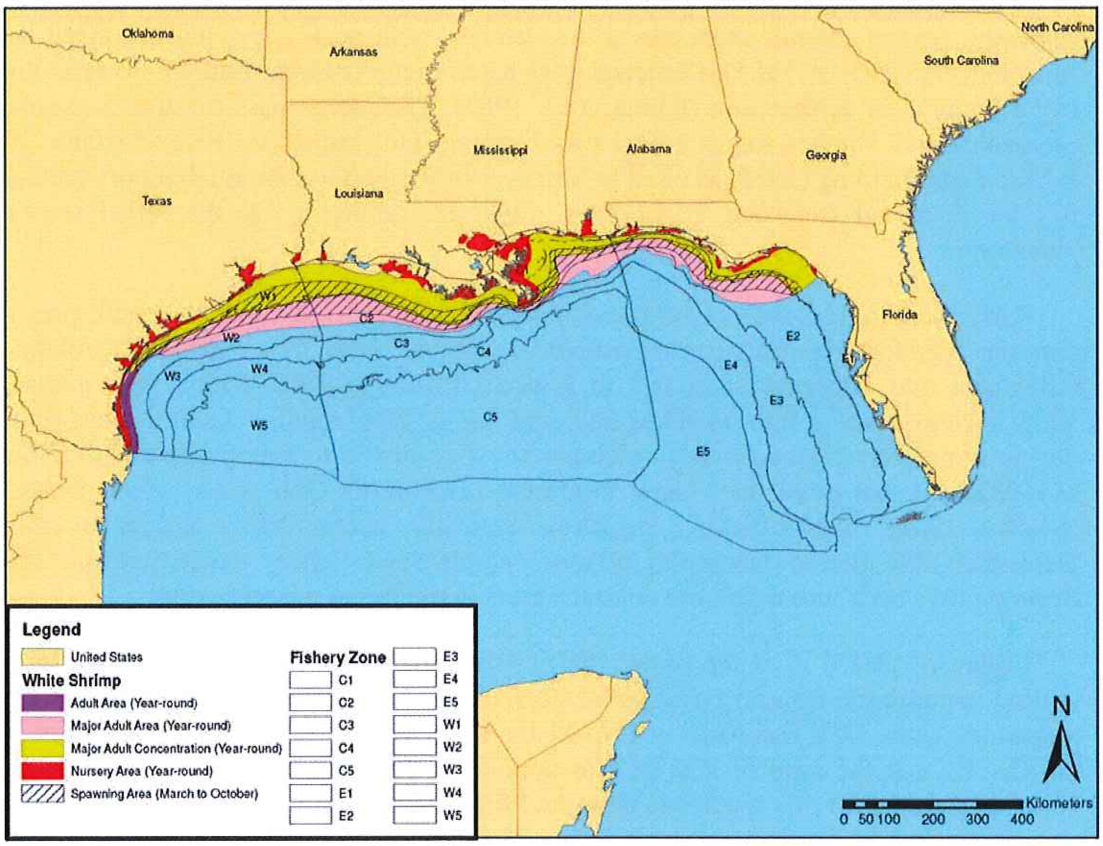


Figure 10. Distribution of the white shrimp in the GOM. Source: NOAA (1985).

White shrimp inhabit waters from the shore to 40 m but are most abundant at depths less than 30 m throughout their range (NOAA 1985). In the northern GOM, the highest densities are off the coast of Louisiana in waters less than 9 m in depth (Klima et al. 1982).

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because the reproductive activities of white shrimp are associated with shallow nearshore estuarine waters of the Gulf inside the 40 m isobath, CWIS assessment is not an issue for this species and no further assessment calculations were done.

Life-History Background

Because the distribution of white shrimp is restricted to nearshore coastal waters of the GOM, offshore CWIS activities are not likely to affect this species. Nevertheless, life-history parameter values have been derived for this species and are detailed below. Life-history data are summarized in Table D2.

White shrimp spawn throughout their range in offshore waters deeper than 8 m. The spawning season extends from March to October, with peak spawning occurring during June and July (NOAA 1985). Demersal eggs hatch into planktonic nauplii larvae within 10 to 12 hours after fertilization (Klima et al. 1982). The larvae pass through 5 naupliar, 3 protozoeal and 3 mysis stages before transforming into postlarvae (Perez-Farfante 1969). Johnson and Fielding (1956, as cited in Muncy 1984) reported that in laboratory studies the full larval period exceeded 10-12 days. Eggs are demersal but the larval stages are planktonic.

Early planktonic larvae begin developing offshore but move onshore with prevailing currents transforming into early post-larvae enroute. The time between hatching and movement into estuaries is about 2 to 3 weeks (Muncy 1984). Within the estuaries the white shrimp develop into juveniles and continue to grow rapidly. Juveniles use estuaries during summer and fall until they reach market sizes of 120 to 160 mm in length (Klima et al. 1982). At that point they begin migrating offshore as Gulf water temperatures cool (Muncy 1984). The offshore migration typically occurs from September through December—the period when the offshore commercial fishery exploits white shrimp. Shrimp move back into nearshore coastal waters in the fall to winter period.

Gallaway (2005) used the brown shrimp stage mortality rates for all stages of white shrimp but adjusted the early post larval stage durations to reflect white shrimp life history Appendix Table D2). Estimates of F to M for white shrimp were taken from Gazey et al. (1982a, b), and the ratio of F to M was applied to the natural mortality rate used in the stock assessment for this species as described for brown shrimp above.

American Oyster (*Crassostrea virginica*)
(Rank 3: Commercial Fishery)

American, or eastern, oysters are found in the western Atlantic from the Gulf of St. Lawrence to the Yucatan Peninsula and throughout the GOM (Figure 11, NOAA 1985). In the GOM, the commercial oyster fishery is the 3rd most valuable ($58.2 million, 23.7 million pounds annually) with about 57% of the harvest occurring in the coastal waters of Louisiana and 25% in Texas (NMFS 2008a).

Oysters are sessile, filter-feeding organisms that are cemented to the substrate by the left valve (Stanley and Sellers 1986). They live in shallow saltwater bays, lagoons and estuaries (0.5 to 7.5 m deep) where salinities range from 5 to 30 ppt. They are intolerant of prolonged exposure to either fresh water or marine salinities. They typically live in aggregations called reefs or beds and prefer hard substrates like pilings, hard rock bottoms, and existing oyster beds.

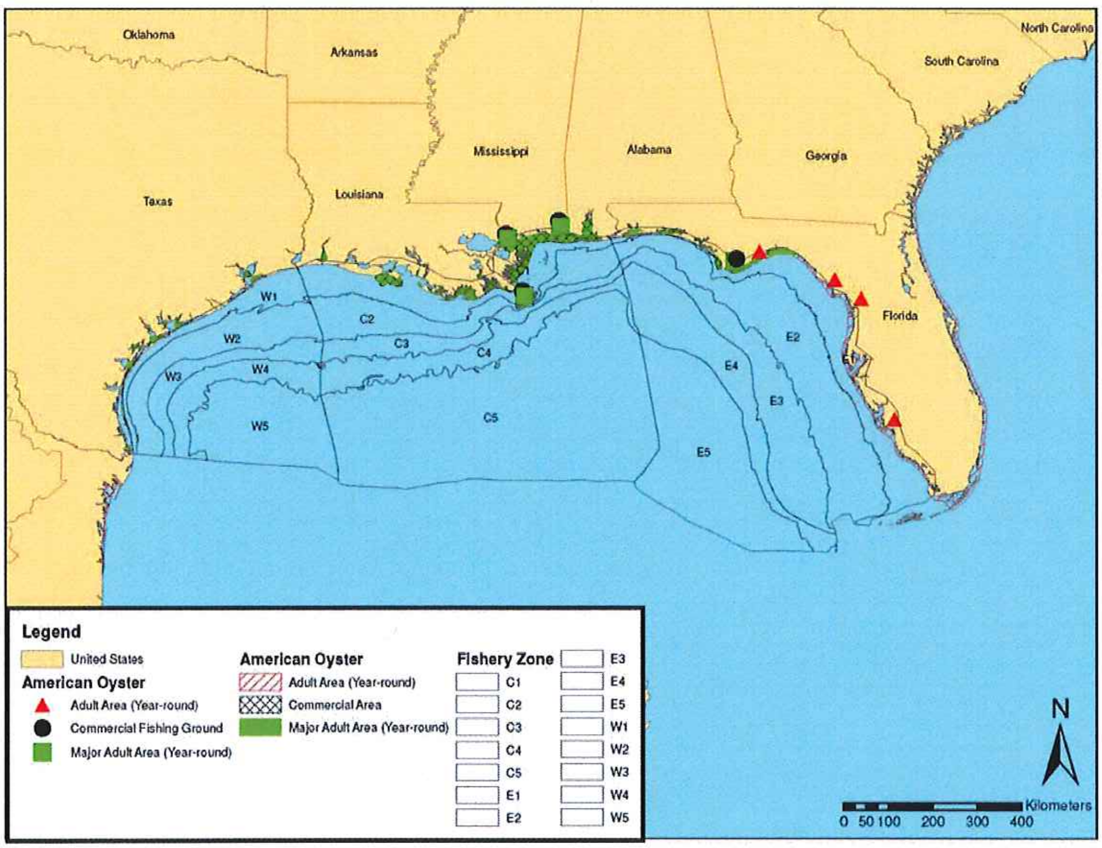


Figure 11. Distribution of the American oyster in the GOM. Source: NOAA (1985).

Adults are dioecious, but often change gender (Bahr and Lanier 1981). Spawning is temperature dependent and in the GOM the temperature must be above 20° C for spawning and above 25° C for mass spawning (Stanley and Sellers 1986). Males initiate spawning by releasing sperm and a pheromone into the water. Females respond to the pheromone by releasing their eggs in a mass event (Bahr and Lanier 1981). Each female may produce from 15 to 86 million eggs per spawning, depending on size, and may spawn several times in one season. Eggs hatch 6 h after fertilization (24° C). Oyster larvae remain in the estuarine water column for 2-3 weeks before settling to the bottom as spat (Bahr and Lanier 1981).

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because oysters and their reproductive output are restricted to shallow, nearshore estuarine waters of the GOM, entrainment by offshore CWIS is not an issue for this species.

Gulf Menhaden (*Brevoortia patronus*) (Rank 4: Commercial Fishery)

The Gulf menhaden is distributed in nearshore marine and estuarine waters out to 120 m from Cape Sable, Florida, to Veracruz, Mexico, with the heaviest concentrations off Louisiana and Mississippi (Figure 12, Lassuy 1983b, NOAA 1985).

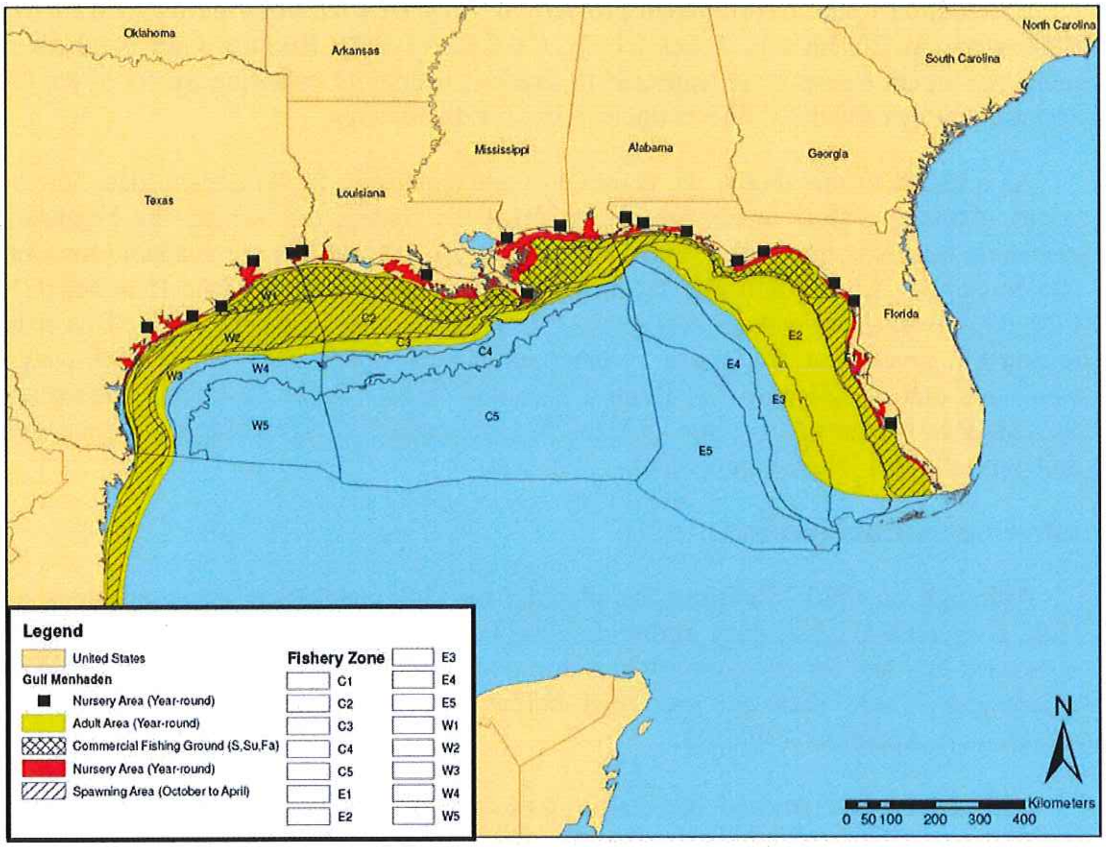


Figure 12. Distribution of Gulf menhaden in the GOM. Source: NOAA (1985).

By weight, the Gulf menhaden fishery accounts for 1.08 billion pounds (71.6%) of the entire 1.5 billion pound GOM commercial fishery, all species combined. The species ranks 4th in dollar value at $54.1 million annually. By weight, over 99.9% of the commercial catch is landed in Louisiana (82.5%) and Mississippi (17.4%) waters. Menhaden are not fished recreationally. Because of its commercial value, the Gulf menhaden has been one of the key indicator species for assessing seawater entrainment losses at GOM LNG facilities (TORP 2006; USCG and MARAD 2005a, 2005b, 2006a, 2006b).

Menhaden are a short-lived fish surviving up to four years with age-1 and age-2 year old fish supporting the bulk of the fishery. Spawning occurs in waters from 2 to 128 m in depth (Roithmayr and Waller 1963) but is concentrated in waters less than 18 m (Lassuy 1983b). Spawning typically occurs from October through March (Turner 1969). Mature females may annually produce from 21,000 eggs for an age-1 fish to 151,000 eggs for an age-4 individual (Lassuy 1983b). Eggs hatch in about two days and larvae may spend up to three to five weeks in offshore waters before moving onshore and entering estuaries (Etzold and Christmas 1979, cited in Lassuy 1983a). It is in these shallow areas that fish mature through their larval phase into juveniles. Adults and maturing juvenile emigrate offshore from mid-summer through the winter.

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because Gulf menhaden and their reproductive output are restricted to shallow, nearshore estuarine waters of the GOM, entrainment by offshore CWIS is not an issue for this species.

As a check to the above, we compiled Gulf menhaden larval density data for the 15 zones. Although, Gulf menhaden spawn primarily during the winter, the beginning of spawning season is in October, and SEAMAP larval density data are available for October and November. Larval Gulf menhaden were reported for only two of the 15 zones (C1 and C2), the two shallow water strata in the Central Planning Area (Table 13). This result is reasonable given that the entire commercial fishery operates in the coastal waters of Louisiana and Mississippi (i.e. Central Planning Area). Table 13 merely multiplies the SEAMAP larval density by zone ($\pm$ 95% CI) times projected water usage to yield estimated daily entrainment. None is projected.

Life-History Background

Although no CWIS facilities are planned for Gulf menhaden spawning areas of the Gulf, considerable life-history information has been compiled for this species including the necessary egg and larval mortality and duration estimate needed for an entrainment loss assessment. These data are presented below. Assessment life-history summaries are presented in Appendix Table D3.

e^2M (2005) first derived life-history parameter values for Gulf menhaden eggs and larvae based upon references to Deegan and Thompson (1987), Deegan (1990), EPA (2002), and personal communications with Dr. Kenneth Rose of Louisiana State University (Appendix Table D4). We know of no information that would improve on those estimates and would use them for any future CWIS analyses. The original e^2M (2005) life-history parameter values for Gulf menhaden have been used in all of the LNG entrainment analyses in the GOM to date (e.g., TORP 2006; USCG and MARAD 2005a, 2005b, 2006a, 2006b).

Table 13. SEAMAP larval densities for Gulf menhaden (± 95% CI) and seawater usage projections by zone. Shaded areas denote the only zones where future CWIS activity is projected. No entrainment is projected.

Zone	Larval Density (no./m3)			Water Usage (Million m3/day)	Daily Entrainment (Millions)		
	Mean	LCL	UCL		Mean	LCL	UCL
E1	0	0	0	0	0	0	0
E2	0	0	0	0	0	0	0
E3	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0
C1	0.098883	0.045678	0.152088	0	0	0	0
C2	0.079485	0.004021	0.154948	0	0	0	0
C3	0	0	0	0	0	0	0
C4	0	0	0	0.05678	0	0	0
C5	0	0	0	0.91986	0	0	0
W1	0	0	0	0	0	0	0
W2	0	0	0	0	0	0	0
W3	0	0	0	0	0	0	0
W4	0	0	0	0.01514	0	0	0
W5	0	0	0	0.17791	0	0	0

Blue Crab (*Callinectes sapidus*)
(Rank 5: Commercial Fishery)

The blue crab is a dominant benthic invertebrate in shallow coastal and estuarine habitats of the GOM and supports major commercial and recreational fisheries (Figure 13, Steele and Perry 1990). In the GOM, the blue crab ranks 5th in terms of commercial landing in dollar value ($43.6 million, 61.1 million pounds annually) accounting for approximately six percent of the Gulf's commercial fishing industry (NMFS 2008a).

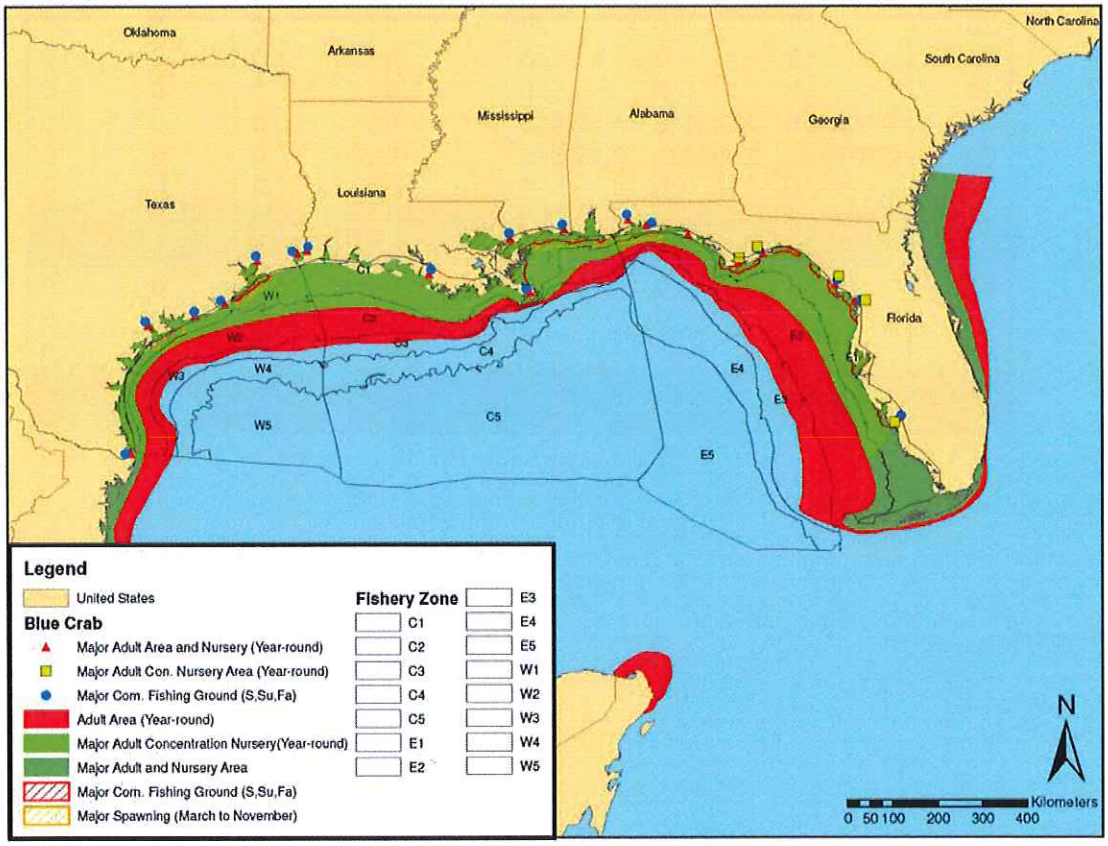


Figure 13. Distribution of blue crab in the GOM. Source: SEAMAP demersal trawl data.

The species is estuarine-dependent and is characterized by high fecundity, high interannual variation in abundance, rapid growth, early reproductive maturity, high natural mortality rates, and a relatively short life span of about 3-4 years (More 1969, Steele and Perry 1990, Van Engel 1987). Crabs reach commercial size about a year after hatching (More 1969) and become sexually mature at about 18 months (Costlow and Bookhout 1959).

Adult blue crabs reside in estuaries where mating occurs year-round. In the GOM, peak periods of mating occur in March-April and June-August, depending on the specific estuary

(Rabalais et al. 1995). During mating, sufficient spermatozoa are implanted in the female to fertilize all the eggs she will lay in her lifetime (Hammerschmidt 1990). The female may remain in the same general area where she mated for a period of weeks to months developing and foraging (Turner et al. 2003). Females then migrate to high-salinity spawning grounds (river mouths, inlets, ocean beaches, barrier islands) but do not move far offshore into oceanic waters. NOAA (1985) delineates blue crab spawning grounds well within the 20-m isobath. Eggs are carried as masses (sponges) attached to swimmerets between the abdomen and body and are carried by the female until they hatch. The number of eggs in a brood ranges from 700,000 to 2 million (Churchill 1919) and females may lay two to three broods each (Epifano 1995). Once the eggs hatch, the zoea larvae are rapidly transported to the open ocean by seaward flowing currents (McClintock et al. 1993).

Larval development occurs in offshore surface waters and includes seven to eight planktonic zoeal stages. At the end of the planktonic zoeal stages, metamorphosis to the megalopae stage occurs. Pattillo and Czapla (1997) report that it takes 31-43 days for development through seven zoeal stages and that 6-12 days were required to develop through the megalopal stage to the first juvenile crab stage. EPA (2002) reported total mortality for these stages combined was 13.8 citing Rose and Cowan (1993). On average these stages occur over a 46-d period.

By the megalopae stage, the crab may either swim or crawl, having developed true legs (Hammerschmidt 1991). Wind-driven onshore currents and tides transport the megalopae to estuaries where they settle in nearshore habitats (Stuck and Perry 1981, Perry et al. 1995, Morgan et al. 1996). Here they develop into juveniles and eventually adults.

Blue crab populations appear to be limited by postsettlement processes that includes predation and fishing mortality. Heck et al. (2001) found little evidence for a significant relationship between megalopal supply and juvenile abundance, except shortly after a few very large episodic recruitment events. Even when such events occurred, the densities of young declined within 14 days to previous background levels. Predation was implicated as being the major factor accounting for the declines. Morgan et al. (1996), likewise found little evidence of density-dependent postsettlement mortality and cited predation as the primary factor limiting blue crab population size.

As stated above, NOAA (1985) delineates blue crab spawning grounds are located in shallow nearshore habitats well within the 20-m isobath (NOAA 1985). Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because blue crabs and their reproductive output are restricted to shallow, nearshore estuarine waters of the GOM, entrainment by offshore CWIS is not an issue for this species.

Life-History Background

Because the distribution of blue crab is restricted to nearshore coastal waters of the GOM, entrainment by offshore CWIS is not likely to affect this species. Nevertheless, life-history parameter values have been derived for this species and are detailed below. Life-history data are summarized in Appendix Table D4.

The blue crab life history schedule was derived from two sources; EPA (2002) and Pattillo et al. (1997).

Because females retain egg masses until they hatch as zoea, the egg stage is not relevant for entrainment analyses. Based upon the life-history characteristics of the species, the remaining stages for the blue crab are (1) larvae (planktonic stage), which comprise the zoea to early juvenile stages; and (2) juvenile/adults. The latter represents all stages after settlement.

EPA (2002) reported total mortality for the zoea-to-juvenile (larval) stages combined was 13.8 citing Rose and Cowan (1993). On average these stages occur over a 46-d period. The daily instantaneous daily rate $M = 13.8 \div 46 = 0.3000\ d^{-1}$. This value is used for the base, low, and high cases. Pattillo et al. (1997) reported that development through seven zoeal stages ranged from 31-43 days and that 6-12 days were required to develop through the megalopal stage to the first juvenile crab stage. Thus, the total period ranged from 37-55 days. The median of 46 days is used as the base case for the stage duration, 37 days as the lower limit estimate of the larval stage duration, and 57 days as the upper limit.

Pink Shrimp (*Farfantepenaeus duorarum*)
(Rank 6: Commercial Fishery)

The pink shrimp is found in coastal waters throughout the GOM but the highest concentrations occur off the southwest Florida coast and on the Campeche Banks off the Yucatán (Figure 14, NOAA 1985).

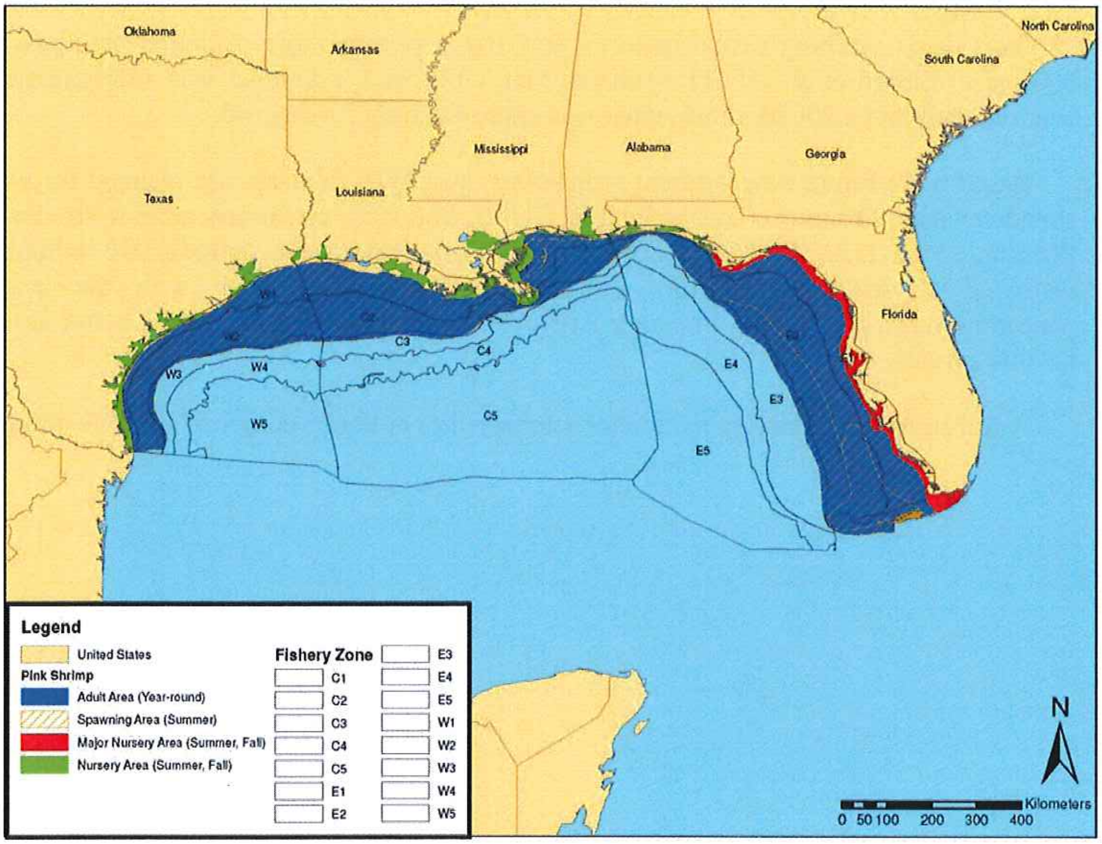


Figure 14. Distribution of pink shrimp in the GOM. Source: NOAA (1985).

The pink shrimp is the 6th most important species taken in the GOM commercial fishery with annual landings averaging 13.2 million pounds worth approximately $27.8 million (NMFS 2008a). Over 83% (dollar value) of the commercial landings are restricted to the western coast of Florida, with the major commercial fishing grounds located off south Florida.

Pink shrimp inhabit continental shelf waters from the shore to 65 m but rarely at greater depths. GMFMC (2004) places maximum depth at 110 m. Spawning occurs in oceanic waters at depths of 4 to 48 m (Perez-Farfante 1969, cited in Muncy 1984). Cummings (1961) found that the Florida population of *Penaeus duorarum* was likely to spawn multiple times. In this population, peak spawning occurred from April through July; however, ripe females were also found at other times of the year. Shrimp weighing between

10.1 to 66.8 g produce 44,000–534,000 eggs (Martosubroto 1974). Eggs are discharged directly into the water column and sink to the bottom (Anderson 1966, cited in Muncy 1984). Eggs hatch into planktonic larvae within 10-12 hours. Non-feeding nauplii undergo five molts within the following 24-36 hours to become free-feeding protozoea. Five nauplial, three protozoeal, and three mysis stage lead to the first post-larval stage (Perez-Farfante 1969, cited in Muncy 1984). The metamorphic period exceeds 10-12 days. Post larvae move onshore into estuaries and begin settlement at about 7 mm. The time between hatching a settlement is 2-3 weeks (Muncy 1984).

Individuals reaching sexual maturity may live a year or more. Aging shrimp based on body size, Eldred et al. (1961) estimated that a 140 mm individual was approximately 1 year old, and that a 200 mm individual was approximately 2 years old.

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3), or for any zone in the Eastern Planning Area (i.e., E1-E5). Because pink shrimp and their reproductive output are restricted to shallow, nearshore estuarine waters of the GOM with the heaviest concentration in the Eastern Planning Area, entrainment by offshore CWIS is not an issue for this species.

A full suite of life-history parameter estimates has not been complied for pink shrimp.

Gulf and Florida Stone Crabs (*Menippe spp.*) (Rank 7: Commercial Fishery)

Gulf stone crab (*Menippe adina*) are found from northwest Florida around the GOM to the state of Tamaulipus, Mexico (Figure 15, FWRI 2008). The Florida stone crab (*Menippe mercenaria*) is found from west central Florida around the peninsula to east central Florida and North Carolina (FWRI 2008). An extensive hybrid zone occurs from the big bend area of Florida to west central Florida, and a smaller hybrid zone occurs from east central Florida through South Carolina.

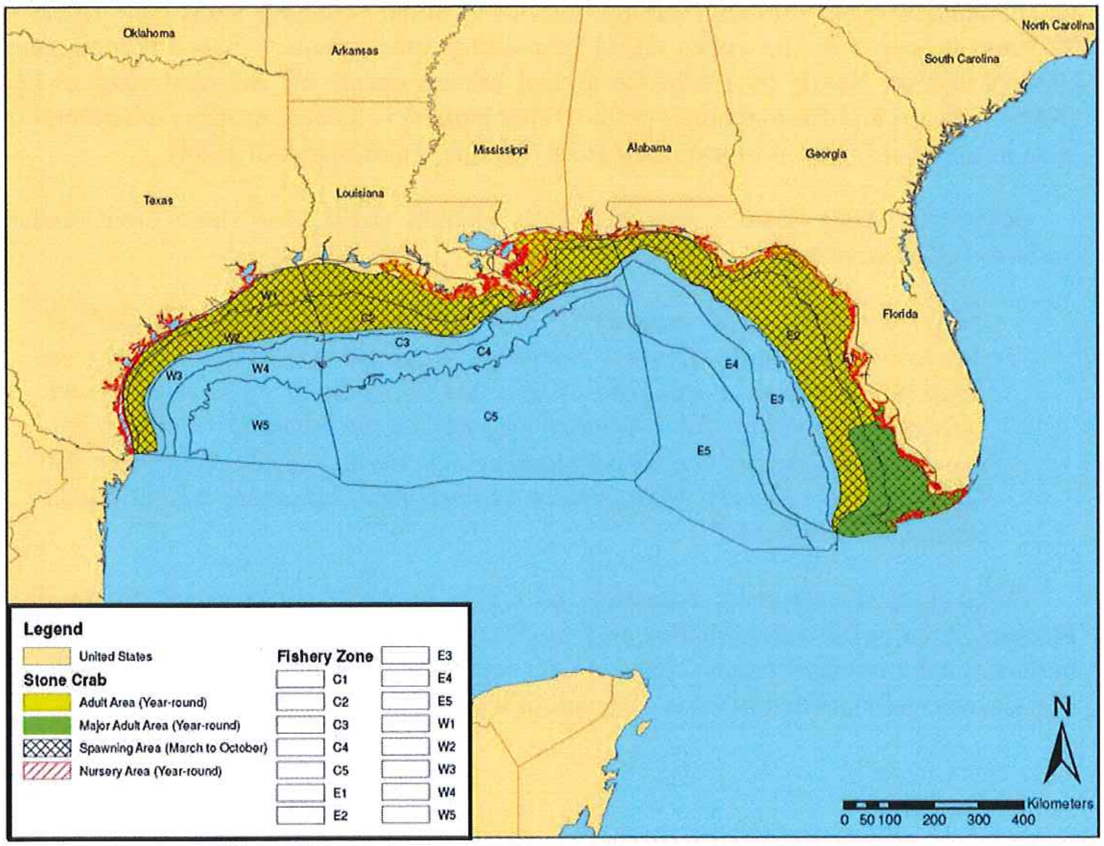


Figure 15. Distribution of stone crab in the GOM. Source: NOAA (1985).

Stone crabs are benthic organisms and adults can be found from the shoreline out to depths of 61 m (GMFMC 2004). They live in seagrass beds, on rocky substrate, mud flats and oyster reefs in nearshore and estuarine area. They also tolerate higher salinity waters. Juveniles can be found nearshore on shell bottoms, sponges, and *Sargassum* mats as well as in channels and deep grass flats. Juveniles also inhabit hiding places such as crevices in and beneath rock or shell.

Stone crabs mate after molting when the female is soft. Males deposit spermatozoa in the receptacle of the female. Eggs are fertilized within the ovary lumen. After fertilization and ovarian development, eggs are deposited in an external mass or sponge (160,000 to 1 million per egg mass) beneath the female abdomen (Lindberg and Marshall 1984). A single female may produce from 4 to 6 sponges per mating season. Eggs usually hatch within nine days to two weeks. Released larvae are planktonic and are found in nearshore coastal waters and within estuaries. Full development takes approximately four weeks before metamorphosis to the juvenile form (Lindberg and Marshall 1984).

The stone crab fishery is unique in that crabs are not killed but rather the claws are removed and the crabs are returned alive to the water. Crabs that survive de-clawing can regenerate new claws through molting. In terms of dollar value, the stone crab fishery is the 7^{th} most lucrative in the entire GOM generating approximately $24.2 million annually (NMFS 2008a). Nearly 99.1% of the annual harvest occurs off the west coast of Florida (NMFS 2008a) and from about 70-90% of that harvest is located at the southern end of the state in the Everglades to Florida Bay areas (Lindberg and Marshall 1984).

(GMFMC 2004) defines Essential Fish Habitat (EFH) for stone crabs under the preferred alternative 6 as:

> *"EFH for stone crab consists of all Gulf of Mexico estuaries: Gulf of Mexico waters and substrate extending from the US/Mexico border to Sanibel, Florida from estuarine waters out to depths of 10 fathoms; water substrates extending from Sanibel, Florida to the boundary between the areas covered by the Gulf of Mexico Fishery Management Council and the South Atlantic Fishery Management Council from estuarine waters out to depths* of *15* fathoms."

Based upon development scenarios, no CWIS facilities are proposed for the Eastern Planning Area or for waters shallower than 200 m in depth. Stone crab populations, and the bulk of the commercial fishery, located off western Florida, and particularly southwestern Florida, are well outside the areas of development and are not a CWIS issue.

Spiny Lobster (*Panulirus argus*)
(Rank 8: Commercial Fishery)

The benthic spiny lobster occupies reefs and rubble areas from the shore out to depths of 80 m or more (Figure 16, NOAA 1985, GMFMC 2004). The commercial lobster market ranks 8th in terms of dollar value at \$20.2 million (3.9 million pounds) annually but all of this catch is reported for western Florida largely in the waters off south Florida and the Florida Keys (GMFMC 2004, NMFS 2008a).

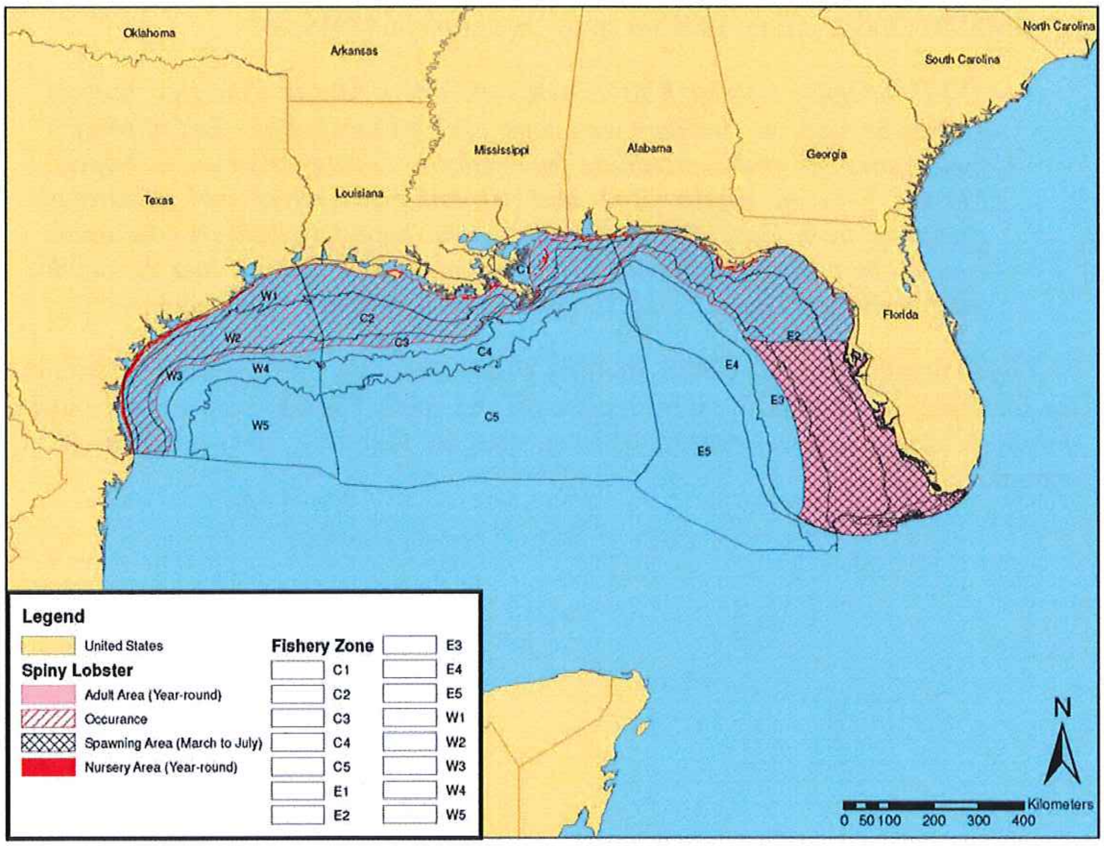


Figure 16. Distribution of spiny lobster in the GOM. Source: NOAA (1985).

The main spawning season for spiny lobster extends from March to July, with a peak in April. Spiny lobsters spawn in offshore waters along the deeper reef fringes (Lyons et al. 1981) and are not known to spawn in shallow waters (Marx and Herrnkind 1986). During reproduction females extrude an egg mass that is retained against the setae of the abdomen where fertilization occurs (Marx and Herrnkind 1986). Fecundity varies with size: females 70-75 mm long may carry 230,000 eggs and females longer than 100 mm may carry over 700,000 eggs. Embryonic development lasts three weeks. Larvae emerge from the egg membrane as phyllosomes (leaf-bodied larvae) and are dispersed into the water column. Larvae develop through 11 stages increasing in size from 2 mm at hatching to 34 mm before metamorphosis. Duration of the planktonic phyllosome stage is 6-12 months. Larvae do not begin actively moving onshore until they metamorphose into postlarval puerulus (Lyons 1980, cited in Marx and Herrnkind 1986).

Phyllosoma larvae inhabit the epipelagic zones of the open ocean, which are characterized by relatively constant temperature and salinity, low turbidity, and adequate transport by oceanic currents (Marx and Herrnkind 1986). Ocean circulation patterns are responsible for dispersing or retaining larvae in spawning areas. Given that all commercial fishing is concentrated in southwestern Florida, the highest concentrations of lobster larvae likely occur in the oceanic waters off the south Florida coast.

GMFMC (2004) defines EFH for spiny lobster in the GOM as:

> *"EFH for Spiny Lobster FMP consists of Gulf of Mexico estuaries south of Tarpon Springs on Florida's west coast except Florida Bay; Gulf of Mexico waters and substrates extending from Tarpon Springs, Florida to Naples, Florida between depths of 5 and 10 fathoms; waters and substrates extending from Cape Sable, Florida to the boundary between the areas covered by the Gulf of Mexico Fishery Management Council and the South Atlantic Fishery Management Council out to depths of 15 fathoms".*

Given that there are no CWIS facilities projected for the entire Eastern Planning Area, the localized distribution of spiny lobster off the south Florida coast is well outside the proposed areas of development. This species is, therefore, not an issue for CWIS entrainment analysis.

Red Grouper (*Epinephelus morio*)
(Rank 9: Commercial Fishery)
And Other Serranidae

The red grouper is found in ocean waters along the western Atlantic coast from Massachusetts to Brazil and throughout the GOM (Figure 17, NOAA 1985). The species is particularly abundant off west Florida.

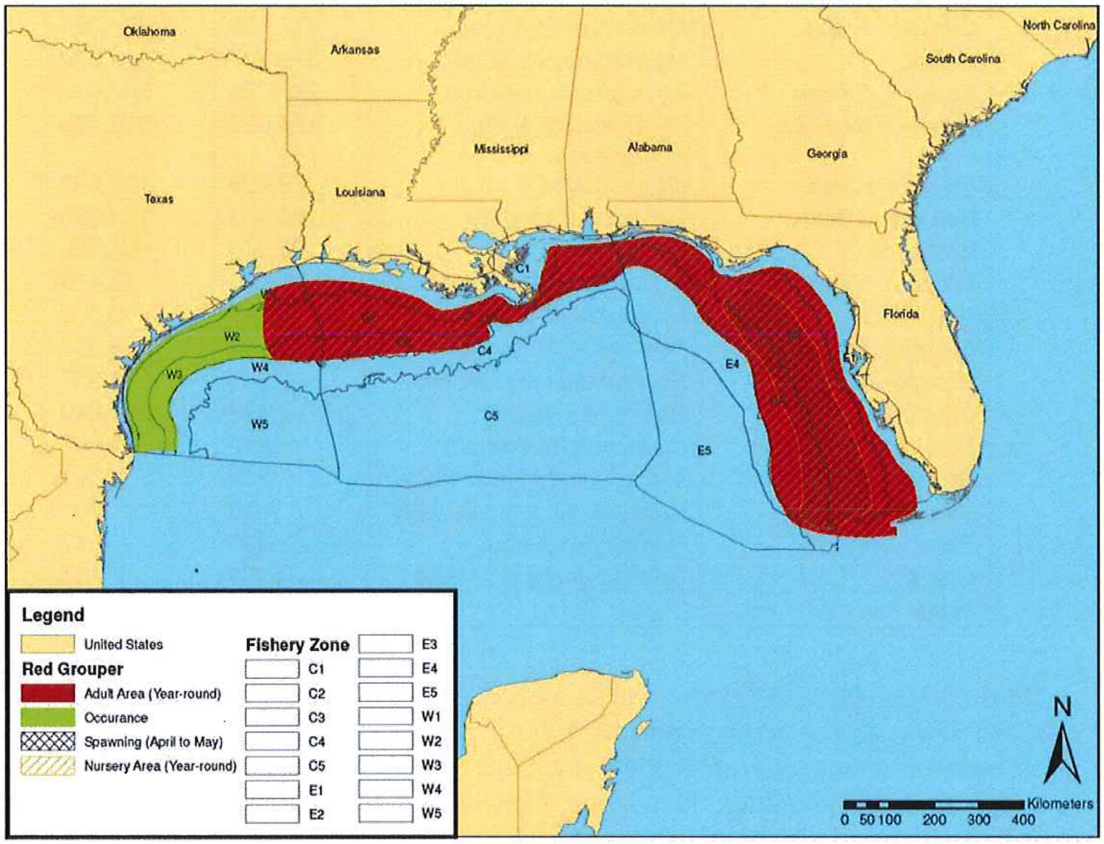


Figure 17. Distribution of red grouper in the GOM. Source: NOAA (1985).

The red grouper belongs to the family Serranidae, which contains groupers, sea bass, and hinds. There are 61 species and 20 genera of Serranidae present in the GOM (McEachran and Fechhelm 2005). Some 16 species are taken commercially where they account for annual landings of about 11.2 million pounds worth some $25 million (Table 14). Four species account for 91.7% of commercial value: red grouper, gag (*Mycteroperca microlepis*), yellowedge grouper (*E. flavolimbatus*) and black grouper (*M. bonaci*). The bulk of the commercial fishery operates off the west coast of Florida: red (99.9%), gag (99.0%), yellowedge (70.8%), black (96.2%).

Table 14. Average annual commercial landings for Serranidae (groupers and sea basses) in the Gulf of Mexico, 2000-2007.

Common Name	Scientific Name	Commercial Landings	
		Pounds	Dollar Value
Grouper, Red	*Epinephelus morio*	6,300,903	12,944,474
Gag	*Mycteroperca microlepis*	2,510,539	6,441,548
Grouper, Yellowedge	*Epinephelus flavolimbatus*	1,017,550	2,658,727
Grouper, Black	*Mycteroperca bonaci*	417,192	1,054,001
Scamp	*Mycteroperca phenax*	325,697	846,620
Grouper, Snowy	*Epinephelus niveatus*	243,299	547,017
Grouper, Warsaw	*Epinephelus nigritus*	164,097	316,489
Hind, Speckled	*Epinephelus drummondhayi*	79,726	165,502
Sea Bass, Black	*Centropristis striata*	161,843	109,325
Groupers	Serranidae	38,315	84,480
Grouper, Yellowfin	*Mycteroperca venenosa*	5,948	13,415
Hind, Red	*Epinephelus guttatus*	5,447	9,202
Grouper, Marbled	*Dermatolepis inermis*	3,009	5,953
Grouper, Misty	*Epinephelus mystacinus*	2,557	5,557
Creolefish, Atlantic	*Paranthias furcifer*	2,193	1,546
Sand Perch	*Diplectrum formosum*	612	1,141
Grouper, Yellowfouth	*Mycteroperca interstitialis*	489	1,061
Hind, Rock	*Epinephelus adscensionis*	425	791
Bass, Longltail	*Hemanthias leptus*	680	667
Graysby	*Cephalopholis cruentata*	64	117
Total		11,276,122	25,202,310

Most Serranidae are benthic and associate with hard bottoms to depths of 200 m, although some species reach depths of 500 m, and others occur on soft bottoms and sea grass beds on continental shelves (McEachran and Fechhelm 2005). Many species are protogynous hermaphrodites, first being females and then turning to males as ovaries transform into testes. Eggs and larvae are pelagic.

Unfortunately the primary data source for larval densities in the GOM (SEAMAP) is virtually useless for CWIS assessments of most grouper. All groupers spawn during a restricted period (Shapiro 1987). Most grouper spawn over a period of 1-5 months and many spawn during a 1-2 month period (18 citations in Shapiro 1987). In the GOM, red grouper spawn during the months of January through April (FLMNH 2008a). This appears to be true of all eight species of the genus *Epinephelus*. During the 26 years for which SEAMAP data is available, representing a total of approximately 7,700 quantitative plankton tows in the northern GOM, *Epinephelus* spp. (eight species combined) larvae have been reported only 19 times and at an average density of only 0.054 larvae/m^3. The SEAMAP program routinely samples from June to November. The sampling program and the spawning season for *Epinephelus* grouper do not overlap.

Based upon general distribution characteristics in the GOM, most Serranidae are found in waters to depths of 200 m. Since no CWIS facilities are proposed for waters shallower than 200 m in depth, the entrainment of Serranidae larvae and eggs would not be an issue.

Red Snapper (*Lutjanus campechanus*) (Rank 10: Commercial Fishery)

The red snapper is found along the western Atlantic from New England to the Yucatan Peninsula, and throughout the GOM (Figure 18). The red snapper is, perhaps, the Gulf's premier food fish. Commercial landings average $10.9 million annually (4.4 million fish) making it the 10th most important species in the fishery. Snapper are the 4th ranking fish taken in GOM recreational fisheries with nearly 3.7 million pounds (963,000 fish) landed annually, not including Texas. An additional 48,000 fish are taken in Texas waters. Total Allowable Catch, or TAC, from 1996 to 2006 over both fisheries was set at 9.12 million pounds per year but was reduced to 6.5 million pounds in 2007 and 5.0 million pounds in 2008 (pers. comm., S. Atran, GMFMC). Szedlmeyer

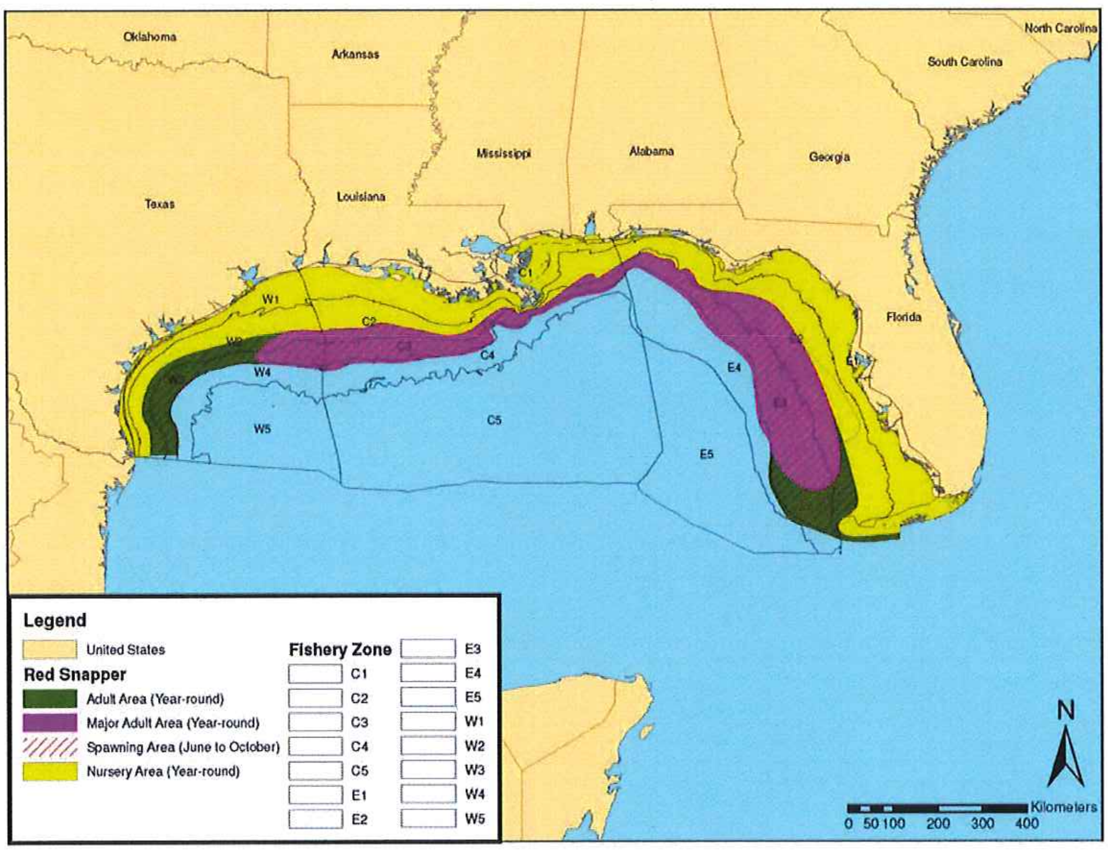


Figure 18. Distribution of red snapper in the GOM. Source: NOAA (1985).

Juveniles (ages 0 and 1) are also taken as bycatch in the shrimp fishery, entering the fishery at about 5 cm in length (Schirripa and Legault 1999). Bycatch harvest has declined in recent years with 9 million juveniles taken in the shrimp fishery in 2003 as compared to about 30 million a decade earlier in 1993 (Stock Assessment Report of SEDAR7 2005). Bycatch mortality has further been reduced by 86% in 2008 relative to the baseline period of 2001-2003 (pers. comm., J. Nance, NMFS).

Spawning occurs in offshore waters and larger individuals are most abundant at depths ranging from 55 to 92 m. Catches of large fish decline both inshore and offshore of these depths (Mitchell et al. 2004). The juveniles are not estuarine-dependent, but after a pelagic larval stage, settle to the bottom in coastal and marine habitats across the western Gulf. Gallaway et al. (1999) observed that high-value habitat for juvenile red snapper in the western Gulf was between 18- and 64-m depths in the offshore region between Mobile Bay, Alabama and Brownsville, Texas. At these juvenile stages, the fish are believed to be strongly attracted to habitats with small relief structures; (e.g., relic shell beds) as observed by Szedlmayer and Howe (1997), Workman and Foster (1994), Szedlmayer and Conti (1999) and others.

The red snapper is a long-lived fish achieving over 50 years of age (Mitchell et al. 2004). The main spawning period occurs in summer (June-August) and individual females at ages 10, 20, and 30 years are capable of producing 20.5, 53.7, and 61.9 million eggs per season, respectively (Schirripa and Legault 1999). The fish matures as early as age 2 which is unusual for such a long-lived fish.

Life Stages, Daily Instantaneous Mortality, Stage Duration

The derivation of life-history values for eggs, larvae and three juvenile stages of red snapper are detailed in Gallaway (2005), Gallaway et al. (2007), and Gallaway et al. (2009). Much of the following is taken from these three papers. Life-history data are summarized in Appendix Table D5.

The egg stage for red snapper is clearly defined and the larval stage duration can be estimated from the ages at which the larvae undergo metamorphosis and settle to the bottom. As discussed below, the pelagic stage lasts for about four weeks. Gallaway (2005) defined the first benthic stage based upon size data. The fish settle to the bottom at lengths of about 16 to 17 mm standard length (SL). Gallaway (2005) extended this stage to about 50 mm SL, which is about the size that the juveniles enter the shrimp trawl fishery. The next two stages are from the estimated end of the juvenile 1 stage to the end of the calendar year (juvenile 2), and the juvenile stage 3 extends from January to June of the next year. The SEDAR 7 Stock Assessment (SEDAR 7 2005) provides an estimate of natural mortality for age 0 fish from size at entry into the shrimp fishery to the end of the year in which the fish were spawned. Another estimate of M is applied to the fish for their second year. We use that rate for larger juveniles. These stages are not intended (other than eggs) to represent true biological stages, but are rather based upon a combination of factors—e.g., size, habitat use, existing data, etc.

Eggs

The egg stage daily instantaneous mortality rate of 0.4984 used for red snapper is based upon Atlantic croaker as originally proposed in e^{2}M (2005). The use of croaker mortality rate as a suitable proxy value for red snapper was supported by Dr. Kenneth Rose of Louisiana State University (as cited pers. comm. in e^{2}M 2005). The duration estimate of 1-day is based largely on studies as cited in e^{2}M (2005). We have found no better estimates and accept these values as reasonable assumptions.

Larval Stage

Rooker et al. (2004) estimated that larval settlement occurred at 16 to 19 mm or 27 to 30 days. Szedlmayer and Conti (1999) suggested metamorphosis at about 18 mm or 26 days. The upper and lower limits of the Rooker et al. (2004) and Szedlmayer and Conti (1999) were used as the low (26 days) and high (30 day) stage duration estimates. The median value of 28 days is used as the base duration estimate.

There is little data regarding natural mortality rates for red snapper larvae. e^2M (2005) used mortality data for the vermillion snapper *Rhomboplites aurorubens* reported by Comyns (1997) as a proxy to estimate red snapper larval mortality rates. Gallaway (2005) did not believe this species was a good proxy for red snapper. First, it is a fall spawner versus the red snapper which is a summer spawner. It settles at a smaller size (5-6 mm versus 16 to 19 mm for red snapper) and has a shorter larval stage duration; i.e., 14 to 16 days versus 26 to 30 days for red snapper. Further, its overall longevity (14 to 20 years) (e.g., Porch and Cass-Calay 2001, Hood and Johnson (1999) is lower than for red snapper which live for over 50 years as observed above. Fecundity is also lower. A 12-in long juvenile vermillion snapper would produce about 8.1 million eggs per season (Porch and Cass-Calay 2001), whereas a 12-in red snapper would produce nearly 16 million eggs per season (Schirripa and Legault 1999). These differences in traits gave Gallaway (2005) cause to question the use of vermillion snapper as a proxy species for red snapper.

To derive the natural mortality rates for larval red snapper, Gallaway et al. (2007) began with an existing estimate of total mortality of red snapper from egg to the size that juvenile red snapper attain when they enter the shrimp fishery; i.e., total mortality for the egg, larval, and juvenile stages combined. McAllister (2004) provides estimates of total mortality for these stages combined which he defines as M_{egg}. The estimates were obtained based upon the average eggs per recruit (without fishing) the equation for the Beverton-Holt α parameter and an assumed value for steepness of the stock-recruit curve for red snapper. M_{egg} was then computed as:

$$S_{egg} = 1/\alpha \tag{1}$$

$$M_{egg} = -\ln(S_{egg}) \tag{2}$$

M_{egg} ranged from a value of 13.3 at an assumed steepness of 0.95, to 15.4 at an assumed steepness of 0.70. Gallaway (2005) used the former value, i.e., 13.3 because nearly all the model runs conducted in the SEDAR 7 Stock Assessment yielded steepness estimates of 0.96 or greater.

Next, using the age-length relationships provided in Rooker et al. (2004), Gallaway (2005) determined the age for red snapper when they enter the shrimp fishery at about 5 cm. He used 51 mm for which the age is about 66 days. Since the larval stage duration was reasonably well known (he used 27 days), the base juvenile 1 stage duration was thus 39 days (66 – 27 days = 39). Rooker et al. (2004) also presented data that can be used to estimate mortality for juvenile 1 fish out to 51 mm or 66 days of age. Gallaway (2005) regressed the $\log_e$ of number at a size on the corresponding age of fully recruited fish from 35 mm SL (age 48.3 days) to 51 mm SL (66.4 days). This yielded an instantaneous daily mortality estimate of 0.1196 with an r^2 of 0.918. He then multiplied this value times 39 days, a total stage mortality of 4.6644 is obtained for the juvenile 1 stage of red snapper.

Gallaway (2005) now had estimates of stage duration, the daily instantaneous rate of mortality and total stage mortality for 2 (eggs and juvenile 1) of the 3 stages contained within McAllister's (2004) total estimate for the three stages combined. By subtraction, he then obtained the total mortality for the larval stage. The value is 8.1378 (13.3 total – 0.4984 egg – 4.6644 juvenile 1). Dividing this value by 27 days yields a daily rate of about 0.3014. Gallaway et al. (2009) subsequently revised total stage mortality to 6.7564, and the median of stage duration to 28 days. These revisions yielded a daily mortality rate of $M = 0.2413\ d^{-1}$. Dividing the total mortality by the upper and lower duration estimates yielded $M = 0.2599\ d^{-1}$ for the low case and $M = 0.2252\ d^{-1}$ for the high case.

Juvenile 1 Stage

The description of how the stage duration and mortality rates were derived for this stage is provided in Gallaway (2005). Gallaway (2005) generated a new regression based upon the data of Rooker et al. (2004) but for a different size range. The mortality estimates were highly conservative because the regression was based upon the last 14 days of the 39-day period; i.e., only the older, larger fish in this stage are included in the regression. Younger fish would be expected to have a higher mortality rate than the older fish used, and the overall rate should, therefore, be somewhat higher than estimated.

Rooker et al. (2004) found the overall growth rates for two cohorts of what Gallaway (2005) defined as the juvenile 1 stage to have been 0.817 mm/d and 0.830 mm/d (average = 0.823). Gallaway (2005) defined this stage as being fish from 17 mm to 51 mm which suggests a length increase of 34 mm over the period. Based upon the mean growth rate, this increase in length suggested a stage duration of 41 days. Szedlmayer and Conti (1999) observed that growth rates for early juvenile red snapper in June and July offshore Alabama ranged from 0.71 to 0.77 mm/day. The size range of fish used in Gallaway's (2005) analysis (~30 to 100 mm SL) was similar to the (~25 to 100 mm SL) size range used to determine growth in Rooker et al. (2004). These independent data suggested that a stage duration of about 38 days or longer was reasonable.

e^2M (2005) uses a base duration of 24 days for this stage, accompanied by a low estimate of 10 days and a high estimate of 31 days. Gallaway (2005) argued that the low estimate was inappropriate. The use of this 10-d period for a comparative analysis of mortality among habitats was not intended by the author to represent an estimate of total stage duration (J. Rooker's letter to B. Gallaway dated 28 April 2005 as cited in Gallaway 2005). The base estimate of 24 days was calculated as the mid point between 47 and 57 days (i.e., 52) less the estimated larval duration of 28 days. There is no basis given for suggesting the end of this stage occurs somewhere between 47 and 57 days.

The regression used to estimate instantaneous daily mortality for juvenile red snapper by Rooker et al. (2004) was based upon fish 47 to 57 days of age. The corresponding size range used by Gallaway (2005) was 34 to 43 mm. If this stage begins at 17 mm SL and one uses 43 mm SL as the size at the end of the stage, the fish increased in length by 26 mm.

Given an average growth rate of 0.823, the estimated stage duration would be on the order of 31.6 days.

If 57 days is arbitrarily used as the base case point estimate of age at the end of this stage, the stage duration should be on the order of 27 to 31 days given e^2M (2005) larval stage duration estimates of 28 (base case), 26 (low duration case), and 30 (high duration case) days. However, Gallaway (2005) provided a rationale for ending this stage at an age of 66 days which corresponds to the size at which the fish begin to enter the shrimp fishery as bycatch. This extends the stage duration estimate to 38 days. Gallaway (2005) assumed the same duration range as for juveniles yielding 36 days for the low case and 40 days for the high case.

Based on Rooker et al. (2004), Gallaway (2005) estimated red snapper juvenile stage 1 instantaneous daily mortality at $M = 0.1196\ d^{-1}$. The standard error of this estimate was 0.0093 which gives (mean $\pm$ 2 SE) a 95% confidence interval of 0.1010 to 0.1382 d^{-1}. These were the daily instantaneous mortality rates for the low and high case. e^2M (2005) used $M = 0.1\ d^{-1}$ as the base estimate based on a personal communication with Dr. Rooker, which is the corrected mean estimate of mortality for early postsettlement period for fish between 47 and 57 days of age. This mortality rate is essentially the same as the Gallaway (2005) base case estimate for fish between 48 and 66 days of age. However, rather than use the 95% confidence interval of this estimate to represent the high and low values of mortality, e^2M (2005) used the extremes observed for individual habitat samples comprising the overall data set. While these are valid individual observations, the individual habitat sample sizes were small (especially those for the inshore habitat where the mortality was estimated to be 0.04) and the habitats were in close proximity to one another. During the peak recruitment period of July 2000 (the year used for mortality estimates), abundance at the inshore habitat was the lowest of any recorded at that habitat for that year, and abundance was higher than observed in July on subsequent sampling trips to this habitat (see Figure 2 in Rooker et al. 2004). In contrast, abundance within the other two habitats peaked in July and declined thereafter. Given these observations, Gallaway (2005) suggested that the best estimates of mortality from the Rooker et al. (2004) studies are the mean and 95% confidence intervals of the mean.

Juvenile 2 Stage

The juvenile 2 stage was defined as red snapper from 66 days old to the end of the year (28 days for larval stage + 38 days for Juvenile 1 stage = 66 days). The period July-December includes 183 days which minus 66 days results in a stage duration of 117 days. The stage duration for the low case was 183 days minus the total for the low stage durations of the larval and juvenile 1 stages (26 + 36 = 62), or 111 days. The stage duration for the high case was 183 days minus the total for the high stage durations of the larval and juvenile 1 stages (30 + 40 = 70), or 113 days.

The annual rate of natural mortality for age-0 red snapper during this period was estimated to be M = 2.0 (Gallaway et al. 2009). The daily instantaneous mortality would thus be $2.0 \div 365$ days = 0.0055. This value was used for the low and high cases.

Juvenile 3 Stage

Based on an annual mortality rate M = 1.6 from Gallaway et al. (2009), the daily instantaneous mortality would thus be $M = 1.6 \div 365$ days = 0.0032 d^{-1}. This value was used for the low and high cases. The duration was the remainder of the year, or 181 days for all cases.

Assessment

In the GOM, red snapper spawn from April to October with the average annual duration of the season being 151 days (Fitzhugh et al. 2004). Across the entire SEAMAP database, 99.2% of all red snapper larvae encounters occur during the months of June through October. The five-month period from June-October equates to 153 days, which is close to the estimate of Fitzhugh et al. (2004), although it is quite likely that densities decrease near the last half of October. For analysis, the spawning period was designated as 151 days. Accordingly, only SEAMAP larval and egg density data for the period June-October are used in the analysis. The estimated stage duration for red snapper larvae is 28 days (Appendix Table D5). Red snapper larvae would therefore be exposed to CWIS entrainment for a total of 179 days (a 151-day spawning season + 28 days duration for the larval stage).

Table 15 lists the larval densities of red snapper (± 95% CI) as derived from the SEAMAP database and projected seawater usage by zone. Of the four zones in which there will be CWIS entrainment, larval red snapper are present in three—C4, C5, and W4. Daily entrainment is calculated for each zone by multiplying density times daily water usage rate to yield daily entrainment. Daily entrainment rates are multiplied times the exposure period of 179 days to yield total entrainment. For the base case, estimated total entrainment ranges from 9,843 larvae in Zone W4 to 105,337 in Zone C5.

As mentioned previously, SEAMAP provides counts of total eggs and does not identify eggs to taxon. Estimation of species-specific egg density assumes that the ratio of species-specific egg density to overall egg density is the same as the ratio of species-specific larval density to overall larval density (all taxa combined). Table 16 lists the average egg density to average total larvae density ratios for each of the three zones. For Zone C4, the egg to larvae ratio is 0.38522. These ratios are then multiplied times red snapper entrainment to yield an estimate of red snapper egg entrainment (Table 17). For the base, or mean density case, it is estimated that, in Zone C4, 26,869 red snapper larvae and 10,350 red snapper eggs would be lost to CWIS entrainment annually.

The number of equivalent eggs (EE)—the number of eggs that had to have been originally produced to account for all of the red snapper eggs and larvae entrained annually in the GOM—was then calculated using the equation of Gallaway et al. (2007):

$$\mathrm{EE} = \frac{E}{\sqrt{S_E}} + \frac{L}{S_E\sqrt{S_L}}, \qquad (3)$$

where E is the number of entrained eggs, L is the number of entrained larvae, and S_E and S_L are the stage survival for the egg and larval stages, respectively. As per Gallaway et al. (2007), equivalent eggs were calculated using base case life-history parameter estimates. The number of equivalent eggs for the mean density case was 6,909,790, with a LCL = 566,899 and an UCL = 13,252,682. These values were then placed into context by computing the number of females of age 5, 10 or 15 years required to produce this level of egg deposition (annual fecundity) obtained from the GOM red snapper stock assessment (SEDAR7 2005) (Table 18).

Gallaway et al. (2008) derived separate stock assessments for red snapper in the eastern and western GOM following SEDAR7 (2005). The eastern Gulf area lies between longitude 86°W and 89°W, the western area between 89°W and 95°W. The red snapper stock is much larger in the western than in the eastern GOM. Since the eastern stock assessment region overlaps with the central CWIS assessment zones used in this report, the impact of the projected entrainment on fishery stocks were examined under two scenarios: the first assuming all the entrainment took place in the eastern stock assessment region, and the second assuming that all the entrainment took place in the western stock assessment region.

Under either stock assessment scenario, the annual entrainment loss of red snapper larvae and eggs under the projected CWIS development scenario would have a trivial impact. Under either assessment scenario, the comparable reproductive output lost is less than a single spawning female among all ages. This reflects the high reproductive output of red snapper coupled with the extremely low entrainment rate. During the spawning season individual females at ages 10, 20, and 30 years are capable of producing 20.5, 53.7, and 61.9 million eggs per season, respectively (Schirripa and Legault 1999). Under the mean density case, only 142,049 larvae and 42,486 eggs are projected to be lost to entrainment.

The low entrainment reflects both the low densities of red snapper in the deepwater regions of the GOM (>200 m) and the relatively low annual seawater intake volume. In their assessment of seven proposed LNG terminals in the GOM, Gallaway et al. (2007) reported that the cumulative water withdrawal rate would be approximately 4 million m^3 per day. For the CWIS scenario the projected total withdrawal rate across all three zones is 0.9918 million m^3 per day. Further, red snapper larval densities for the LNG assessment ranged from 0.0063 to 0.0517 larvae/m^3. For this study they range from 0.00064 to 0.00363 m^3, roughly an order of magnitude less. In fact, the highest intake rate of 0.91986 m^3 per day in Zone C5 corresponded to the lowest larval density observed at 0.00064 individual/ m^3.

Table 15. SEAMAP red snapper larval densities (+ 95% CI), seawater usage estimates by zone, and estimated larval entrainment. Daily entrainment is calculated by multiplying density times daily water usage rate to yield daily entrainment. Daily entrainment rates are multiplied times the exposure period of 179 days to yield total entrainment.

Zone	Larval Density (no./m3)			Water Usage (Million m3/day)	Daily Entrainment			Total Entrainment Over 179 Days of Exposure		
	Mean	LCL	UCL		Mean	LCL	UCL	Mean	LCL	UCL
E1	0.0000	0.0000	0.0000	0	0	0	0	0	0	0
E2	0.0171	0.0070	0.0272	0	0	0	0	0	0	0
E3	0.0089	0.0025	0.0153	0	0	0	0	0	0	0
E4	0.0009	0.0000	0.0018	0	0	0	0	0	0	0
E5	0.0000	0.0000	0.0000	0	0	0	0	0	0	0
C1	0.0066	0.0000	0.0132	0	0	0	0	0	0	0
C2	0.0324	0.0240	0.0408	0	0	0	0	0	0	0
C3	0.0103	0.0061	0.0144	0	0	0	0	0	0	0
C4	0.0026	0.0010	0.0043	0.05678	150	54	246	26,869	9,658	44,081
C5	0.0006	0.0000	0.0013	0.91986	588	8	1,168	105,337	1,515	209,159
W1	0.0034	0.0006	0.0062	0	0	0	0	0	0	0
W2	0.0482	0.0346	0.0618	0	0	0	0	0	0	0
W3	0.0299	0.0207	0.0390	0	0	0	0	0	0	0
W4	0.0036	0.0002	0.0071	0.01514	55	3	107	9,843	461	19,226
W5	0.0000	0.0000	0.0000	0.17791	0	0	0	0	0	0

Table 16. Ratio of average egg density to average larval density (all taxa combined).

Zones	Average Egg Density	Average Larval Density All Taxa	Ratio Egg to Larval Density
C4	0.2946	0.7645	0.38522
C5	0.0985	0.3504	0.28106
W4	0.1313	0.5110	0.25697

Table 17. Estimated annual entrainment of red snapper eggs by zone. Values are derived by multiplying red snapper larval density times the egg to total larvae ratio.

Zone	Component	Daily Entrainment		
		Mean	LCL	UCL
C4	Larval Entrainment	26,869	9,658	44,081
	Egg/Larval Ratio	0.38522	0.38522	0.38522
	Egg Entrainment	10,350	3,720	16,981
C5	Larval Entrainment	105,337	1,515	209,159
	Egg/Larval Ratio	0.28106	0.28106	0.28106
	Egg Entrainment	29,606	426	58,787
W4	Larval Entrainment	9,843	461	19,226
	Egg/Larval Ratio	0.25697	0.25697	0.25697
	Egg Entrainment	2,529	119	4,940
Total	Larval Entrainment	142,049	11,633	272,465
	Egg Entrainment	42,486	4,264	80,708

Table 18. Impact of red snapper entrainment based upon GOM stock assessments SEDAR7 (2005) as presented in Gallaway et al. (2007). Separate stock assessments have been derived for the red snapper in the eastern and western GOM.

	East			West		
	Low	Base	High	Low	Base	High
Entrained Equiv. Eggs (millions)	0.57	6.91	13.25	0.57	6.91	13.25
Equiv. Age-5 Females	0	0	1	0	0	1
Equiv. Age-10 Females	0	0	0	0	0	0
Equiv. Age-15 Females	0	0	0	0	0	0
Geom. Mean Stock (million eggs)	6,595,738	6,595,738	6,595,738	28,179,097	28,179,097	28,179,097
Entrained Stock (%)	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000
Equilibrium at Last Available (2003) Stock Size						
Eggs-per-Recruit (millions)	1.773	1.773	1.773	0.869	0.869	0.869
Eggs (millions)	9,314,990	9,314,978	9,314,967	14,328,720	14,328,714	14,328,709
Recruits	5,254,067	5,254,065	5,254,064	16,494,162	16,494,159	16,494,156
Yield-per-Recruit (lbs)	0.301	0.301	0.301	0.181	0.181	0.181
Yield (lbs)	1,582,271	1,582,271	1,582,270	2,987,031	2,987,031	2,987,030
Lost Yield (lbs)	0	0	1	0	1	1
Lost Yield (%)	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Maximum Sustained Yield						
Eggs-per-Recruit (millions)	11.68	11.68	11.68	4.41	4.41	4.41
Eggs (millions)	74,978,866	74,978,791	74,978,717	115,501,820	115,501,791	115,501,763
Recruits	6,420,179	6,420,179	6,420,179	26,212,787	26,212,786	26,212,786
Yield-per-Recruit (lbs)	0.473	0.473	0.473	0.223	0.223	0.223
Yield (lbs)	3,037,661	3,037,661	3,037,661	5,841,546	5,841,546	5,841,546
Lost Yield (lbs)	0	0	0	0	0	0
Lost Yield (%)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Yellowfin Tuna (*Thunnus albacares*)
(Rank 11: Commercial Fishery)

The yellowfin tuna occurs in tropical and subtropical water of the western Atlantic including the GOM (Figure 19). It is an oceanic, pelagic fish that generally occurs beyond 200-m depths (NOAA 1985). Yellowfin move into the northern GOM as water temperatures rise, and retreat southward when temperatures decline. They are present in the southern Gulf throughout the year.

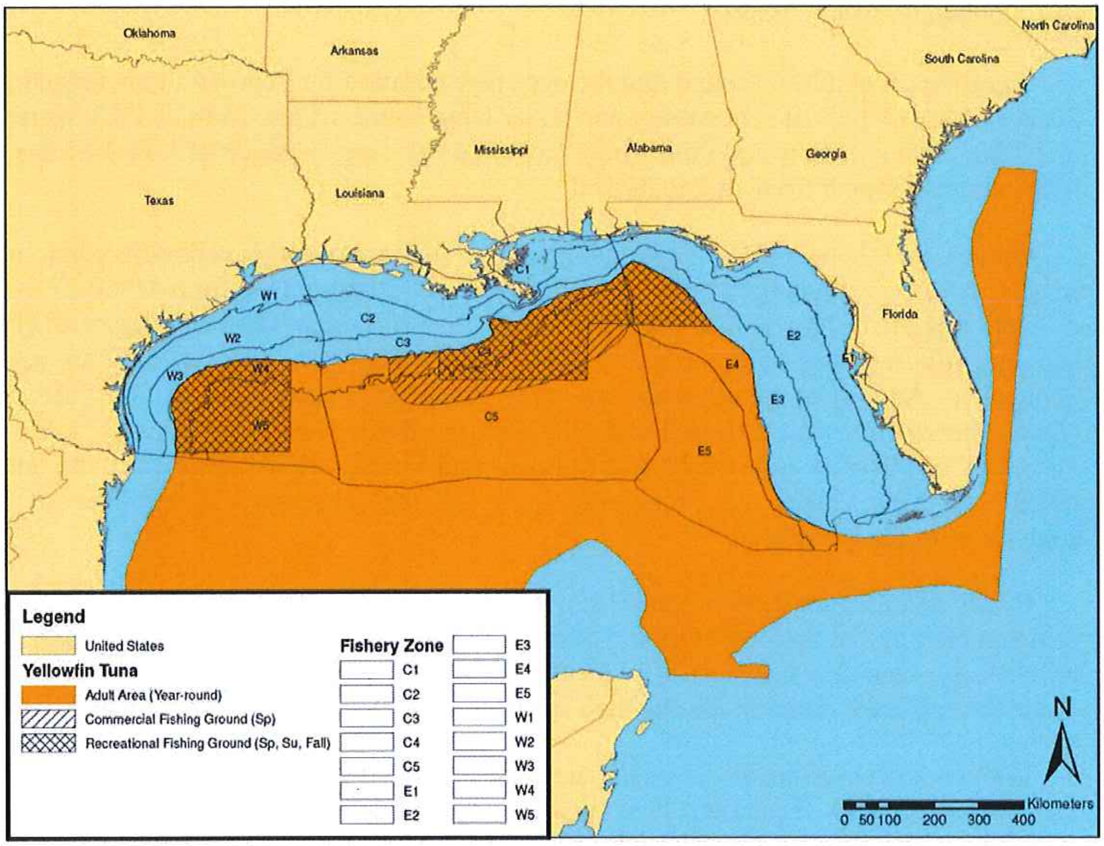


Figure 19. Distribution of yellowfin tuna in the GOM. Source: NOAA (1985).

Seven species of tuna are taken commercially in the GOM: albacore (*Thunnus alalunga*), bigeye (*T. obesus*), blackfin (*T. atlanticus*), bluefin (*T. thynnus*), little tunny (*Euthynnus alletteratus*), skipjack (*Katsuwonus pelamis*), and yellowfin (NMFS 2008a). Collectively, tuna landings in the GOM would rank 10th overall averaging \$11.2 million annually (3.9 million pounds). Yellowfin tuna dominate the commercial harvest, comprising 94% (\$10.5 million, 4.4 million pounds) of the total dollar value of all seven species combined. The yellowfin harvest is limited to Louisiana (81.2%), western Florida (11.0%), and Texas (7.8%). The higher harvest in Louisiana may be tied to the fact that significant numbers of yellowfin tuna spawn near the Mississippi River discharge plume (Grimes and Lang 1992).

Of the seven species of tuna, the majority of life-history data has been compiled for the yellowfin tuna. The yellowfin tuna is a large, epipelagic, oceanic fish that lives above and below the thermocline but is generally found in the upper 100 m of the water column (FLMNH 2008b). They can reach 200 cm in length (McEachran and Fechhelm 2005) and have a life span of about seven years (NMFS 2008c). Yellowfin tuna are common in the GOM beyond the 900-m isobath (Springer 1957). In the GOM spawning takes place between May and September (McEachran and Fechhelm 2005). Female yellowfin are multiple spawners, with an average annual spawning frequency of 46 times or about one spawn every three days (NMFS 2008c). Females have an average of 1 million to 4 million eggs per batch (NMFS 2008c).

Margulies et al. (2007) found that the egg stage duration for yellowfin tuna ranged from 20 to 28 h (0.83-1.17 d) depending upon water temperature (range 24.0-29.5°C). Harada et al. (1980, cited in Pauley and Pullin 1988) reported egg stage duration of 1.34-1.85 days for temperatures ranging from 18.7 to 30.1°C.

Grimes and Lang (1992) reported larval mortality rates for yellowfin tuna in the Mississippi River discharge plume in the northern GOM that ranged from $M = 0.27$ to 0.43 d^{-1}, with a pooled average of $M = 0.33\ d^{-1}$. Analyzing the same data set, Lang et al. (1994) subsequently reported daily mortality rates that ranged from 0.16 in July to 0.41 in September. Additional larvae daily mortality rates have been reported for little tunny (*Euthynnus alletteratus*) collected in the Mississippi River plume ($M = 0.95\ d^{-1}$) and near Panama City, Florida ($M = 0.72\ d^{-1}$) (Allman and Grimes 1998). However, the authors noted that these values were unusually high and that necessary assumptions of their analysis were likely violated.

Houde and Zastrow (1993) compiled a list of larval stage durations for some 81 species of fish including five species of tuna: yellowfin (25.1 days), bluefin (27.9 days), little tunny (24.4 days), southern bluefin (24.1 days), and skipjack (20.2 days). No estimates were found for egg stage duration for any tuna species.

With parameter estimates for egg stage duration, larval stage duration, larval stage daily mortality rate, and fecundity, it is possible to conduct fecundity-hindcasting CWIS entrainment assessments for yellowfin tuna provided that an adequate proxy value for an egg stage daily mortality rate can be determined for the species.

Fecundity

When reproductively active, yellowfin tuna continuously release batches of hydrated oocytes at regular intervals (Hunter et al. 1986). Annual fecundity is a function of batch fecundity (i.e., the number of eggs produced during each spawning event) and the number of spawning events per year. Schaefer (1998) demonstrated that female yellowfin produce twice their body weight in spawn each year. Their annual egg production exceeds the standing stock of oocytes within the ovaries at any given time (Schaefer 1996).

Dr. Larry Barnthouse[1] derived fecundity estimates for Atlantic yellowfin tuna using life-history parameters from the 2008 Atlantic yellowfin tuna stock assessment (Table 19).

Table 19. Egg production estimates for yellowfin tuna derived from life-history parameters from the 2008 Atlantic yellowfin tuna stock assessment.

Age	Fecundity	M yr^{-1}	F yr^{-1}	Lx	Egg Production
3	2,308,745	0.6	0.3965	1	106,202,249
4	4,586,336	0.6	0.5930	0.30331	63,989,747
5	6,214,742	0.6	0.2220	0.13332	38,113,388
6	7,065,417	0.6	0.2220	0.058601	19,045,931
			Lifetime		227,351,315

Most yellowfin are capable of reproduction at the age of 2 or 3 years and can live to 6-7 years of age (NMFS 2008e). For stock assessment purposes, Atlantic yellowfin are assumed to mature at age 3 (ICCAT 2008). Egg projection are for tuna ages 3-6. The estimates are also based on the assumption that Atlantic yellowfin spawn approximately 46 times per season or about one spawn every three days (NMFS 2008e). Egg production estimates take into account natural and fishing mortality by age class. Based upon the 2008 Atlantic yellowfin tuna stock assessment the net lifetime reproductive output for a 3-year-old female Atlantic yellowfin tuna is approximately 227 million eggs.

Egg Stage Mortality

In a study of the effects of temperature and size on the development and mortality rates of the early life history stages of marine fish, Pepin (1991) derived a general model equating egg mortality and temperature based upon data compiled for 18 species of marine fish:

$$M_e = 0.030e^{0.18T} \tag{4}$$

where M_e is the daily instantaneous mortality of the eggs and T is temperature in °C. Offshore surface waters in the GOM fluctuate between approximately 24° to 29°C on a seasonal basis (Temple et al. 1977). Using a median temperature 26.5°C, a general daily egg mortality of 3.54 d^{-1} was estimated.

Assessment

It is extremely difficult to identify larvae of yellowfin tuna to species level. Of the 1,541 SEAMAP ichthyoplankton tows containing members of the species *Thunnus*, 1,075 were identified as *Thunnus* spp. and only five as *T. albacares* (Table 20). There are four species of *Thunnus* that could comprise the category *Thunnus* spp. For assessment purposes, we assumed that all larvae identified as *Thunnus* sp. in the SEAMAP database were actually yellowfin tuna. This is obviously an overestimate since members of the three

[1] Dr. Larry Barnthouse served as a consultant and stock assessment analyst for the yellowfin tuna section.

other species of *Thunnus* spp. likely contribute to total count. This assumption would mean that any subsequent CWIS entrainment assessment would error on the conservative side. This seemed the most prudent approach.

Table 20. Number of SEAMAP ichthyoplankton tows containing tuna larvae of the genus *Thunnus*.

Scientific Name	Common Name	SEAMAP Tows
Thunnus spp.		1,075
Thunnus albacares	Yellowfin tuna	5
Thunnus atlanticus	Blackfin tuna	175
Thunnus obesus	Bigeye tuna	1
Thunnus thynnus	Bluefin tuna	285

In the GOM, the peak spawning period for yellowfin tuna is believed to be May-September (NMFS 2008e).This equates to a spawning period of 153 days. Assuming a base larval stage duration of 16 days (Appendix Table D7), Total entrainment exposure would total 169 days.

Table 21 lists the larval densities of yellowfin tuna as derived from the SEAMAP database and projected seawater usage by zone. Daily entrainment is calculated for each zone by multiplying density times daily water usage rate to yield daily entrainment. Daily entrainment rates are multiplied times the exposure period of 169 days to yield total entrainment. For the base mean entrainment case, estimated total entrainment ranges from 32,889 larvae in Zone W4 to nearly 1.2 million in Zone C5.

The egg ratio (see Red Snapper section for details) was calculated by dividing total average egg density across Zones C4, C5, W4, and W5 by average total larval density (all taxa) across Zones C4, C5, W4, and W5. The ratio for this case was 0.1960. This ratio was multiplied times total yellowfin entrainment to yield total egg entrainment. (Table 22).

Lastly, the number of equivalent eggs was calculated using the methods described in the Red Snapper section based upon Gallaway et al. (2007) (Table 23). From those results the number of female spanner equivalent were calculated assuming that egg production is 227 million eggs per female(Table 24). For the proposed development scenario, annual entrainment loss for the mean intake case is the reproductive output of 29 female spawners.

Table 21. SEAMAP yellowfin tuna larval densities (+ 95% CI), seawater usage estimates by zone, and estimated larval entrainment. Daily entrainment is calculated by multiplying density times daily water usage rate to yield daily entrainment. Daily entrainment rates are multiplied times the exposure period of 169 days to yield total entrainment.

Zone	Larval Density (no./m3)			Water Usage (Million m3/day)	Daily Entrainment			Total Entrainment Over 169 Days of Exposure		
	Mean	LCL	UCL		Mean	LCL	UCL	Mean	LCL	UCL
E1				0	0	0	0	0	0	0
E2				0	0	0	0	0	0	0
E3				0	0	0	0	0	0	0
E4				0	0	0	0	0	0	0
E5				0	0	0	0	0	0	0
C1				0	0	0	0	0	0	0
C2				0	0	0	0	0	0	0
C3				0	0	0	0	0	0	0
C4	0.01389	0.00829	0.01950	0.05678	789	471	1,107	133,330	79,541	187,119
C5	0.00762	0.00616	0.00908	0.91986	7,010	5,667	8,353	1,184,695	957,725	1,411,665
W1				0	0	0	0	0	0	0
W2				0	0	0	0	0	0	0
W3				0	0	0	0	0	0	0
W4	0.01286	0.00683	0.01889	0.01514	195	103	286	32,899	17,469	48,329
W5	0.00981	0.00330	0.01632	0.17791	1,745	588	2,903	294,969	99,364	490,575

Table 22. Estimated annual entrainment of yellowfin tuna larvae and eggs. Egg values are derived by multiplying yellowfin tuna larval density times the egg to total larvae ratio.

Component	Daily Entrainment		
	Mean	LCL	UCL
Larval Entrainment	1,645,894	1,154,099	2,137,688
Egg/Larval Ratio	0.1960	0.1960	0.1960
Egg Entrainment	322,611	3,720	16,981

Table 23. Estimates number of yellowfin tuna equivalent eggs (millions) lost to entrainment by zone.

Zone	LCL	Mean	UCL
C4	309	518	726
C5	3,718	4,599	5,480
W4	68	128	188
W5	386	1,145	1,904

Table 24. Number of yellowfin tuna equivalent spawners assuming Atlantic fecundity estimate of 227 million eggs per female.

Zone	LCL	Mean	UCL
C4	1	2	3
C5	17	21	25
W4	0	1	1
W5	2	5	9
Total	21	29	38

Sharks and Rays

The commercial landings of sharks and rays throughout the GOM averages about $2.8 million annually (2000-2007), which collectively ranks the group 17th in terms of dollar value (NMFS 2008a). Landings include 15 species of shark and several species of rays. The reproductive strategy of all these species precludes them from consideration for CWIS entrainment analysis. All of these species are either viviparous (bearing small numbers of live young), ovoviviparous (eggs hatch in the womb or immediately after extrusion), or aplacental-viviparous (young feed on less developed embryos and eggs in the uterus [oophagy]). None have planktonic egg or larval stages and therefore are not subject to entrainment in CWIS. These species are not relevant to assessment of seawater intake entrainment impacts.

Red Drum (*Sciaenops ocellatus*)
(Rank 1: Recreational Fishery)

The red drum is an estuarine-dependent species that inhabits shelf waters of the western Atlantic Ocean and the GOM (Figure 20, Pattillo et al. 1997). The greatest concentrations are in Louisiana and Texas. It is the dominant recreational species taken in the GOM averaging over 13 million pounds (2.8 million fish) annually (ex Texas). An additional 264,000 drum are taken annually in Texas waters. About 74% of all red drum are taken off Louisiana and most fisheries are concentrated in State waters. In 1987, the Federal government prohibited all commercial harvesting of red drum in the EEZ under emergency H.R. 4690 (GMFMC 2004). The GMFMC followed with Amendments 1 and 2 to their red drum FMP permanently banned commercial fishing in the EEZ (GMFMC 2004). Individual states followed suit and by 1988 the Gulf-wide commercial harvest had been largely eliminated. Only a small residual fishery remains in Mississippi (NMFS 2008a). As a result, the red drum ranks 104th in the overall Gulf commercial fishery with average annual landings worth a mere $34,000.

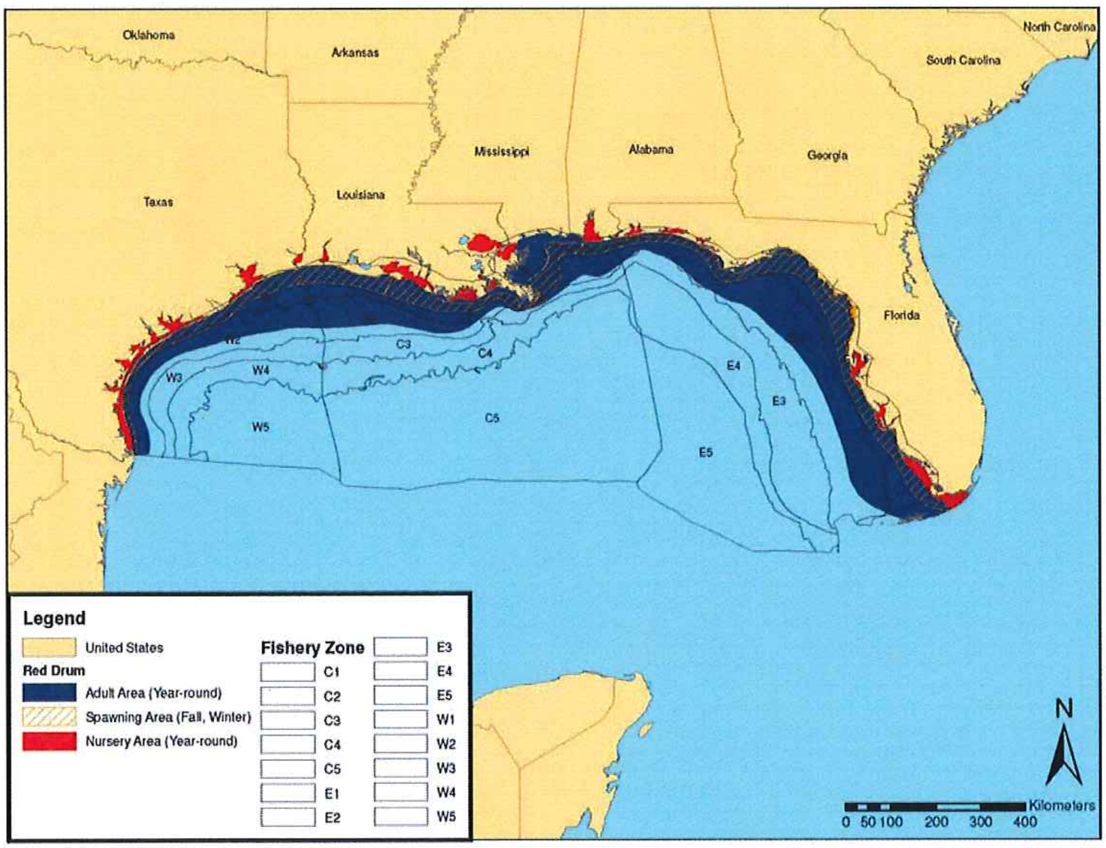


Figure 20. Distribution of red drum in the GOM. Source: NOAA (1985).

Spawning occurs in nearshore coastal waters, typically from mid August to mid October with a peak in September (e.g., Ditty et al. 1988, Comyns 1997, Wilson and Nieland 1994). In the northwestern Gulf, spawning occurs in nearshore waters and evidence suggests that mature adults congregate near the mouths of passes and inlets (Pearson 1929, Peters and M^{c}Michael 1987, Comyns et al. 1991). While females can mature as early as age 2 (fraction mature = 0.05), the fraction mature does not achieve 90-100% until ages 5 and 6. Based upon Porch (2000), a 6-year-old female would produce on the order of 8.3 million eggs annually, whereas a 10-year-old female red drum produces on the order of 16 million eggs annually. The life span of red drum extends to at least age 30. Thus, red drum has a long life span and is characterized by high fecundity.

Eggs and yolk-sac larvae are planktonic and are transported onshore where post larvae settle in seagrass beds, wetlands and estuaries (Reagan 1985). The young rear in these nursery grounds reaching their juvenile stage. Adults tend to travel in schools close to the shore, however, some larger fish remain in the open Gulf year round (Reagan 1985).

Table 25 lists the SEAMAP larval densities of red drum ($\pm$ 95% CI) and seawater usage projections by zone. The distribution of red drum larvae is restricted to the nearshore depth zones 1-3 (0-200 m) for the Central and Western Planning Areas and depth zones 1-2 (0-60 m) for the Eastern Planning Area. This pattern is consistent with the observations of Gallaway et al. (2007) who found that, based upon an analysis of SEAMAP data, the density of larval red drum in the GOM decreased exponentially with distance from shore. This pattern is exemplified in the Central Planning Area. There is better than a 93% decrease in red drum density from zones C1 to C2 and another 70% decrease from zones C2 to C3. Based on these species distribution data, no new CWIS are anticipated for red drum spawning areas and entrainment impacts from offshore CWIS are not an issue for this species

Life-History Background

Red drum have been the focus of intense scientific study for many years. Considerable life-history information has been compiled for this species including the necessary egg and larval mortality and duration estimate needed for an entrainment loss assessment. These data are presented below. Assessment life-history summaries are presented in Appendix Table D7.

The derivation of life-history values for eggs, larvae and three juvenile stages of red snapper are detailed in Gallaway (2005). Much of the following is taken from Gallaway (2005).

Table 25. SEAMAP larval densities for red drum (± 95% CI) and seawater usage projections by zone. Shaded area denoted the only zones where future CWIS activity is projected. No entrainment is projected.

Zone	Larval Density (no./m3)			Water Usage (Million m3/day)	Daily Entrainment (Millions)		
	Mean	LCL	UCL		Mean	LCL	UCL
E1	0.4370516	0.1941797	0.6799235	0	0	0	0
E2	0.0079176	0.0022171	0.0136181	0	0	0	0
E3	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0
C1	0.7700569	0.4935585	1.0465553	0	0	0	0
C2	0.0513088	0.0277172	0.0749004	0	0	0	0
C3	0.015419	0	0.03182	0	0	0	0
C4	0	0	0	0.05678	0	0	0
C5	0	0	0	0.91986	0	0	0
W1	0.8754962	0.3860068	1.3649855	0	0	0	0
W2	0.1270838	0.0903891	0.1637785	0	0	0	0
W3	0.0023236	0.0005137	0.0041335	0	0	0	0
W4	0	0	0	0.01514	0	0	0
W5	0	0	0	0.17791	0	0	0

Gallaway (2005) noted that the identification of larval and juvenile stages of red drum are actually based on a combination of size, habitat-use, and seasonal abundance patterns as opposed to being true biological stages. The planktonic larval stage covers the size range from hatch (1.5 to 2 mm SL to 8 mm SL). The planktonic stage is followed by an early benthic or juvenile 1 stage which he defined as the size range from 8 to 24 mm SL. These individuals mainly utilize seagrass beds or other vegetated areas as habitat. Up to 24 mm SL, the early benthic juveniles are fully vulnerable to the benthic sled plankton sampling gear (e.g., Rooker et al. 1999), but sizes ≥25 mm SL are not fully vulnerable. It is about this size that juvenile red drum appear in shoreline bag seine studies (e.g., Scharf 2000). Gallaway (2005) thus assumed that the second juvenile stage began at about 25 mm SL. These larger juveniles were subdivided into two groups—juvenile 2 and juvenile 3. The first stage covers the period from October to March (juvenile 2) and the second (juvenile 3) is for juveniles from April to August. August is the end of the first year, assuming spawning occurred in September of the previous year. This division was used because a marked reduction in mortality is evident for the larger juvenile red drum that occur in April-June as compared to the smaller juveniles present in October-March (Scharf 2000).

Eggs

The egg stage daily instantaneous mortality rate of 0.4984 used for red drum is based upon Atlantic croaker as originally proposed in e^2M (2005). The use of croaker mortality rate as a suitable proxy value for red drum was supported by Dr. Kenneth Rose of Louisiana State University (as cited pers. comm. in e^2M 2005). The duration estimate of 1-

day is based largely on laboratory studies as cited in e^2M (2005). We have found no better estimates and accept these values as reasonable assumptions.

Larval Stage

e^2M (2005) used 20 days as the base, high and low duration period (i.e., no variation) for the larval stage of red drum, citing Rooker et al. (1999) and Stunz et al. (2002). Rooker et al. (1999) noted that peak densities of benthic settlers were observed for individuals 8-9 mm (corresponding ages = 20-24 d), suggesting that recruitment to seagrass meadows follows a planktonic period of approximately 20 days. Gallaway (2005) suggested that the median of 22 days be used for the base estimate, and that 20 and 24 days be used as the low and high estimates, respectively. This would be consistent with Rooker et al.'s (1999) observation that full recruitment to the first benthic juvenile stage occurred at ages from 20 to 24 days.

e^2M (2005) used 0.25, 0.33 and 0.17 as the base, high, and low estimates of daily instantaneous mortality, respectively. These values are derived from Comyns (1997) as described in Table G-13 in e^2M (2005). Gallaway (2005) disagreed with the use of 0.17 d^{-1} as the low estimate and 0.33 d^{-1}as the high estimate. The 0.17 d^{-1} value was from a single cruise where more than one cohort was represented in the collections and because of this artifact it is not a reliable estimate for the low end of the range. The value 0.33 d^{-1} was Comyns' (1997) best estimate for larvae in the 2-5 mm range, not the high end of the size range. If 0.17 d^{-1} is used as the low end, then the highest value observed on a cruise should be used for the high end estimate. However, neither of these estimates would be appropriate because they were based on incomplete sampling. In contrast, Comyns et al. (1991) reported a mean estimate of 0.51 d^{-1} (SE = 0.207) for larval red drum collected in 1984 and 1985 in the Mississippi Bight area east of the mouth of the Mississippi River. This value should also be considered as a candidate for the high value.

Gallaway (2005) recommended that M = 0.3009 d^{-1} be used for the base case based upon the following. Comyns (1997) value of M = 0.33 d^{-1} was assumed to be the best estimate for larvae 2-5 mm. Gallaway (2005) used a value of M = 0.1365 d^{-1} for early stage benthic juveniles (see below). The value M = 0.233 d^{-1} represents a linear interpolation between 0.33 d^{-1} and the 0.1365 d^{-1} value for larvae between 6 and 8 mm. Using the average of the total mortality obtained by applying these rates to the respective size intervals yields an estimate of 0.3009 d^{-1}. The upper and lower bounds (0.2225 and 0.3793) were calculated using Comyns' (1997) 95% confidence interval for the 0.33 estimate.

Gallaway (2005) submitted his estimates of larval red drum instantaneous mortality rates and those proposed by e^2M (2005) to Dr. Comyns for his evaluation. Dr. Comyns concluded (Gallaway 2005, Appendix 1) that the Gallaway (2005) estimates were more realistic than those proposed by e^2M (2005). Dr. Comyns also noted that the value of Z = 0.17 was not a reliable mortality estimate and the high estimate of 0.33 was likely somewhat understated.

Juvenile 1 Stage

Gallaway (2005) concurred with the estimates of the daily instantaneous mortality rates (base, high, and low) being used for this life history stage by e^2M (2005) based on Rooker et al. (1999). Gallaway (2005) disagreed with the base and low stage duration estimates being used by e^2M (2005); i.e., 12 days for each. The high end estimate of 20 days seemed appropriate. Based upon Rooker et al. (1999), Gallaway (2005) concluded that the stage duration likely ranged between 17 and 20 days with the median estimate being about 18.5 days. His view was that the 12-day period referenced in Rooker et al. (1999) was not intended to be interpreted as the total stage duration, but was rather a common time frame used to make direct comparisons of mortality rates between 1994 and 1995. Gallaway (2005) submitted his argument to Dr. Rooker (Gallaway 2005, Appendix 2).

Dr. Rooker confirmed that the 12-d period over which red drum mortality rates were estimated was not intended to define a specific stage in the life history of an individual, but instead was an interval over which a reliable estimate of mortality could be determined (Gallaway 2005, Appendix 2). He noted that the upper end of the interval is on the order of 40 days and that even this is not intended to define the end of the postsettlement stage. If the planktonic stage extends to ages 20 to 22 days and 40 days is a minimum estimate of age near the upper end of this stage, then the duration of this stage should range between 18 and 20 days.

Gallaway (2005) used Rooker et al.'s (1999) age-length relationships to calculate age at the beginning and end of the size range included within this stage to estimate stage duration. One can evaluate these estimates by using observed growth rates (mm/day) to estimate the days required to achieve the growth between the size of fish at the beginning and end of the stage. In 1994, the observed increase in size was 16 mm (i.e., 8 mm SL to 24 mm SL, Rooker et al. 1999). Rooker et al. (1999) observed a growth rate of 0.58 mm/d in 1994. This yields a duration estimate of about 28 days. In 1995, the observed increase in size was 15 mm (9 mm to 24 mm SL) and the growth rate was 0.62 mm/d (Rooker et al. 1999). The estimated stage duration would thus be about 24 days. However, if one uses 20 mm SL as the maximum size, the total growth for each year would be 12 and 11 mm, respectively. These values yield stage durations of 20 and 18 days, respectively.

Independent evaluations of postsettlement red drum growth rates are provided by Rooker and Holt (1997) based on data obtained from the Aransas Estuary, Texas during September to December 1994. Growth for six successive cohorts ranged from 0.50 to 0.82 mm/d, averaging 0.63 mm/d (95% CI = 0.54 to 0.72 mm/d). Applying this estimate to the observed 16 mm (24 mm end point) increase yields an estimated stage duration of 25 days; this value applied to a 12 mm increase (maximum size of 20 mm) yields an estimate of 19 days. However, the data used by Rooker and Holt (1997) is a large part of the data set used by Rooker et al. (1999). Therefore, it is not truly an independent data set.

However, Stunz et al. (2002) reported an overall postsettlement growth rate of 0.45 mm/d for 10 to 33 mm SL red drum in Galveston Bay, Texas. To eliminate the potential effects of movement among habitats, they evaluated the growth of fish in enclosures around oyster-reef, non-vegetated bottoms, salt marsh, and seagrass habitats. The observed growth rates were 0.12, 0.21, 0.40, and 0.42 mm/day, respectively. Growth rates in enclosures approximated natural growth rates. These growth rates would suggest a longer stage duration than was estimated above.

Based upon these data, (Gallaway (2005) proposed that a conservative stage duration estimate for postsettlement red drum was 18.5 days with a range of 17 to 20 days.

Juvenile 2 Stage

e^2M (2005) used 0.0054 (0.00478 to 0.00609) as the instantaneous mortality rate for this life stage based upon Scharf (2000). They observed that those values are the mean and 95% CI's of reported daily mortalities for 20 years and nine Texas estuaries from Sabine Lake to the Laguna Madre as reported by Scharf (2000). The corresponding stage durations used by e^2M (2005) were 166 for the base and low duration cases, and 162 days for the maximum stage duration. These are calculated values for one half of the remainder of the first year. The other half is assigned to the Juvenile 3 stage discussed below.

Scharf's (2000) estimates of mortality were calculated from the observed declines in CPUE that occurred from the peak values observed in fall and winter (November/December) to the end of spring. The stage begins in October, but these juvenile fish were not fully recruited to fishing gear until November and December, and the peak usually occurred in December. Thus, overall the stage duration covered a 273-d period with the mortality estimates based upon a subset of the data from December (typically) through June. Since the smallest sizes were not covered by the analysis, mortality is likely somewhat underestimated. Further, arbitrarily reducing the stage duration period to only 166 days rather than using the 212 days over which the regressions were calculated, or the 273 days over which the ≥25 mm SE stage occurs, is not explained or justified in e^2M (2005).

Apparent mortality based upon CPUE declines does appear to be typically higher in the December-March periods as compared to April-June periods (Scharf 2000). Gallaway (2005) restricted the mortality estimates to data from Sabine Lake and Galveston Bay as these Texas estuaries are closest to the central part of the red drum range. He then used Figure 4 in Scharf (2000) to calculate survival based on the December and March CPUE values, and converted survival to a daily mortality rate for each estuary (i.e., total mortality ÷121 days in the sample period). Using this approach, Gallaway (2005) obtained a daily instantaneous mortality rate of 0.0079 for Galveston Bay and 0.0108 for Sabine Lake. These constituted high and low ends of the range and the median (0.0094) was used for the base case.

Based on Scharf (2000), Gallaway (2005) estimated this stage extends from October-March (180 days). Up to now, we have accounted for 41.5days (from egg to the juvenile 1 stage) which occur in the September/October period. Thus, for the base case, the duration of the juvenile 2 stage is estimated at 168.5 days (180 days-11.5 days in October). In the low case above, egg to the juvenile 1 stage occurs over a total of 38 days (September plus 8 days in October). The stage duration for the low duration estimate is 180 days-8 or 172 days. Similarly, the high case described above extends for 45 days. This would allocate 15 days in October; 180-15 yields a stage duration of 165 days.

Juvenile 3 Stage

Like e^2M (2005), Gallaway (2005) used the Porch (2000) red drum stock assessment to approximate the daily instantaneous mortality rate ($M = 0.0018\ d^{-1}$) for the balance of the age-0 year (155 days).

Adults

Estimates for adult natural and fishing mortality (Appendix Table D8) are those derived by (EPRI 2005).

Spotted Seatrout (*Cynoscion nebulosus*)
Rank 2: (Recreational Fishery)

The spotted seatrout is found in nearshore waters of the GOM (Figure 21) inhabiting sandy bottoms, seagrass beds, and estuaries (McEachran and Fechhelm 2005). This species ranks 2nd in the GOM recreational fishery with 13.0 million pounds landed annually. The annual landing by weight is almost identical to that of red drum (13.1 million pounds); however, 10.7 million seatrout are taken annually compared to only 2.8 million red drum. The spotted seatrout is the premier game fish in Texas waters with more than 996,000 fish landed annually.

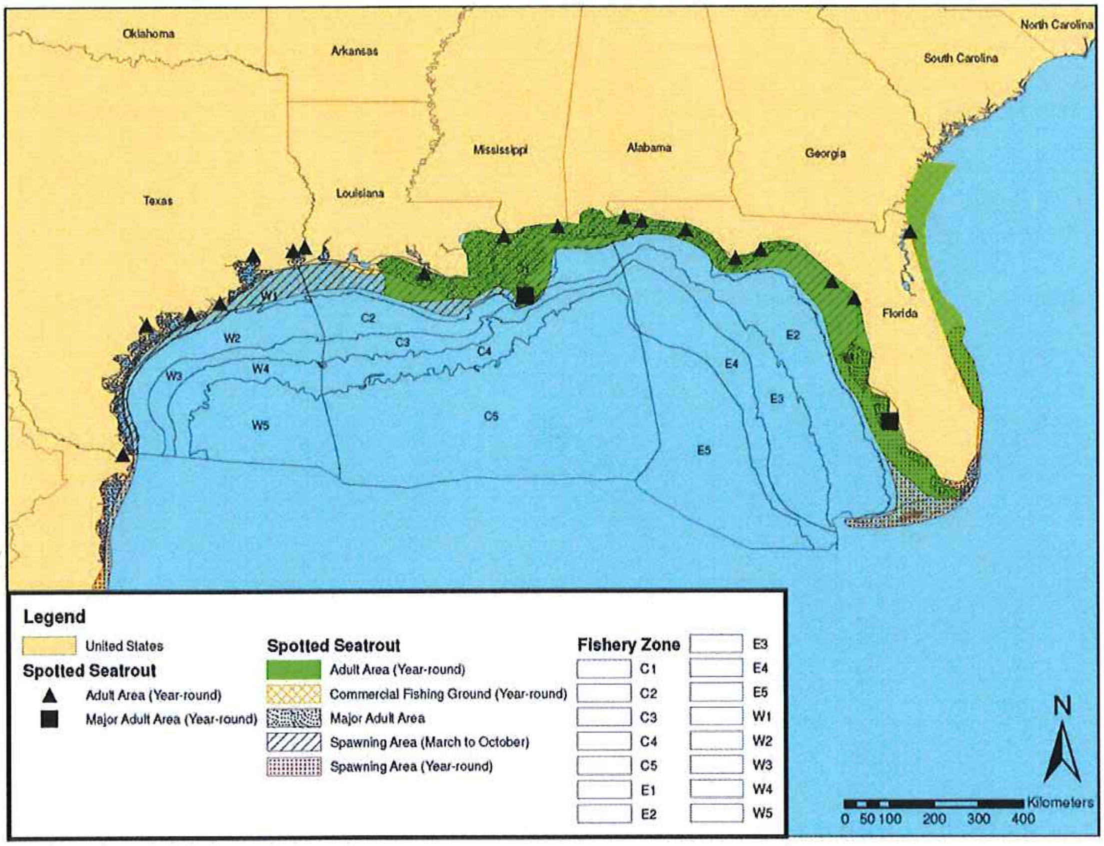


Figure 21. Distribution of spotted seatrout in the GOM. Source: NOAA (1985).

Spotted seatrout are most common in the shallow bays during spring and summer. As water temperatures decline during fall, fish move into deeper bay waters and the GOM. As water temperatures warm in the spring the fish move back into the shallows of the primary and secondary bays (TPWD 2008). Spotted seatrout reaches sexual maturity at one to two years. A female spotted seatrout may spawn several times during the season. Younger females may release 100,000 eggs and older, larger females may release a million eggs (TPWD 2008). Spawning occurs within estuaries and offshore to depths of only 3-4 m (Lassuy 1983c). They prefer shallow grassy areas where eggs and larvae have some cover from predators.

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because the reproductive activities of spotted seatrout are associated with shallow nearshore estuarine waters of the Gulf inside the 20 m isobath, entrainment by offshore CWIS is not an issue for this species.

Sheepshead (*Archosargus probatocephalus*)
Rank 3: (Recreational Fishery)

The sheepshead occurs along the coast and in estuaries and brackish water throughout the GOM (McEachran and Fechhelm 2005. This species ranks 3rd in the GOM recreational fisheries, excluding Texas, with over 4.5 million pounds landed annually (1.7 million fish). An additional 74,000 fish are taken each year in Texas. Commercially, sheepshead rank 36th with about $671,000 in annual landings totaling in excess of 2.0 million pounds.

The euryhaline sheepshead prefers brackish waters and can be found inshore around rock pilings, jetties, mangrove roots, and piers as well as in tidal creeks (FLMNH 2008b). It seeks out warmer spots near spring outlets and river discharges and sometimes enters freshwater during the winter months. This fish moves to offshore areas in later winter and early spring for spawning, which sometimes occurs over artificial reefs and navigation markers. Juveniles live in seagrass flats and over mud bottoms.

In the GOM spawning occurs primarily from January through May (FLMNH 2008b). Adults migrate to offshore waters to spawn, later returning to nearshore waters and estuaries. Spawning frequency ranges from once a day to once every 20 days. Little is known regarding spawning behavior. Females may produce from 1,100 to 250,000 eggs per spawning event (FLMNH 2008b). One study determined that those fishes found closer to shore averaged 11,000 eggs per spawning event while those offshore averaged 87,000 eggs per batch. The buoyant eggs are approximately 0.8 mm in diameter and hatch in 28 hours following fertilization at 23°C (FLMNH 2008b).

Although sheepshead move offshore to spawn the distances involved are likely not great. In the entire SEAMAP database, there are only five recorded quantitative plankton tows that have taken either *Archosargus probatocephalus* or *Archosargus* sp. Densities ranged from 0.01 to 0.07 larvae/m^3 and were taken over a depth range of 15 to 35 m.

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because the reproductive activities of sheepshead are associated with very shallow nearshore estuarine waters of the Gulf inside the 35 m isobath, entrainment by offshore CWIS is not an issue for this species.

Red Snapper (*Lutjanus campechanus*)
Rank 4: (Recreational Fishery)

See listing under commercial fishery.

Gag Grouper (*Mycteroperca microlepis*) Rank 5: (Recreational Fishery) And Other Serranidae

The gag grouper belongs to the family Serranidae, which contains groupers, sea bass, and hinds. There are 61 species and 20 genera of Serranidae present in the GOM (McEachran and Fechhelm 2005). Over 3.5 million pounds (483,000 fish) of gag are taken annually in the GOM recreational fishery. No landings are reported for Texas. Gag also ranks 14th in the GOM commercial fishery with over 2.5 million pounds landed annually worth approximately $6.4 million.

Residing in brackish to marine waters, the gag grouper is found offshore on rocky bottom as well as inshore on rocky or grassy bottoms to depths of 152 m. It is common on rocky ledges along the eastern GOM (FLMNH 2008c). All of the six other species of *Mycteroperca* grouper in the GOM occur in coastal waters inside the 150 m isobath (McEachran and Fechhelm 2005).

Gag spawn from January through May in the GOM and the South Atlantic Bight at offshore spawning grounds. There is a major spawning ground on the west Florida Shelf (FLMNH 2008c). As is the case discussed previously for red and other *Epinephelus* grouper, the spawning periods for gag and other *Mycteroperca* grouper do not overlap with the June-November SEAMAP sampling program. During the 26 years for which SEAMAP data is available, representing a total of approximately 7,700 quantitative plankton tows in the northern GOM, *Mycteroperca* spp. (seven species combined) larvae have been reported only six times and at an average density of only 0.054 larvae/m^3.

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because gag are associated with shallow nearshore waters of the Gulf inside the 152 m isobath, entrainment by offshore CWIS is not an issue for this species.

Spanish Mackerel (*Scomberomorus maculatus*)/ King Mackerel (*S. cavalla*) Rank 6 and 7: (Recreational Fishery)

The king mackerel is found along the western coast of the Atlantic Ocean from Massachusetts to Rio de Janeiro, Brazil and the GOM (Figure 22). The Atlantic Ocean and GOM stocks mix in south Florida waters (FLMNH 2008d).

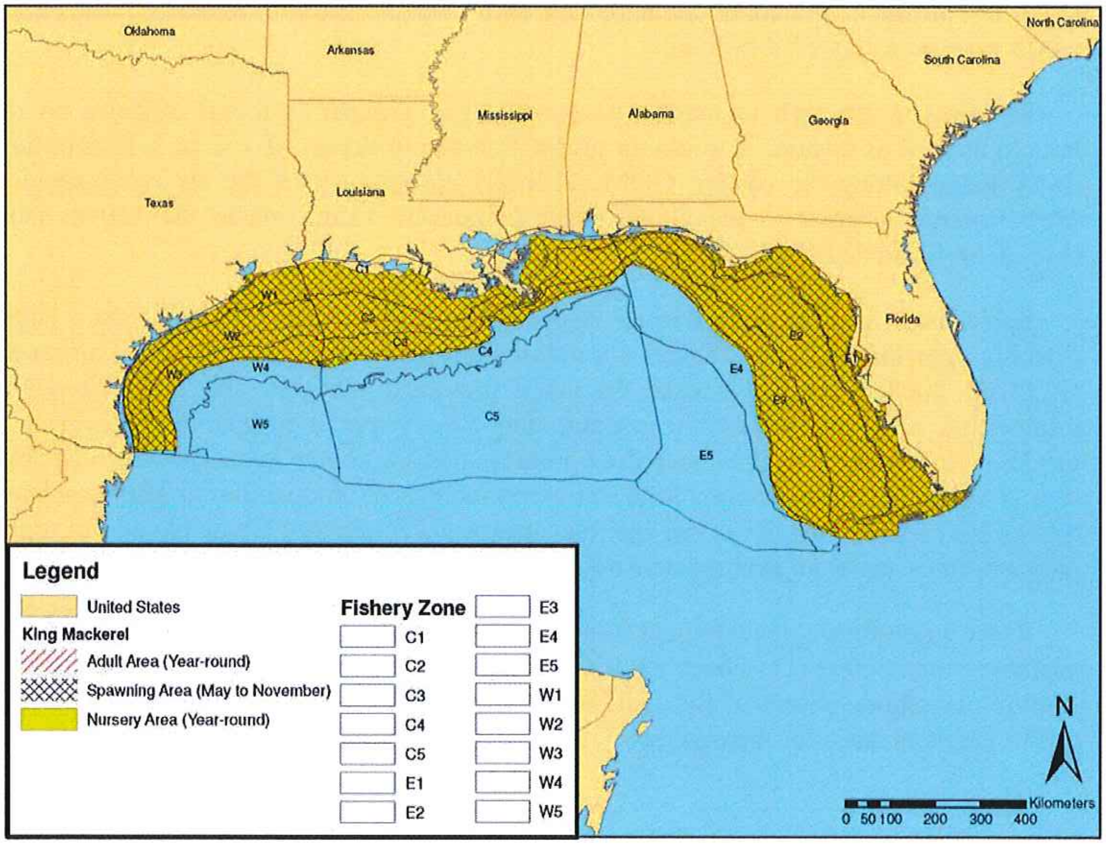


Figure 22. Distribution of king mackerel in the GOM. Source: NOAA (1985).

The king mackerel ranks 7th in the GOM recreational fishery with nearly 2.7 million pounds (310,000 fish) landed annually. Approximately 96% of annual catch by weight occurs off Alabama (25%) and western Florida (71%). An additional 20,000 fish are landed annually in Texas waters. The species ranks 24th in the GOM commercial fishery with annual landings worth $1.2 million. The king and cero mackerel complex is worth an additional $1.5 million (reported together by NMFS 2008a). The majority of commercial landing occur off Louisiana and western Florida.

The king mackerel is a pelagic fish that is found from the shore out to 200 m depths (NOAA 1985). Large schools in the northern hemisphere migrate northward during vernal warming and southward during autumnal cooling (McEachran and Fechhelm 2005). King mackerel migrate from south Florida to the northern GOM in spring, and back again in fall

(NOAA 1985). Resident populations may exist off Louisiana and Florida (McEachran and Fechhelm 2005).

Little is known about the reproduction of king mackerel (FLMNH 2008d). In the GOM, spawning occurs most frequently during May through September. Eggs are believed to be released and fertilized continuously during these months, with a peak between late May and early July with another between late July and early August.

The Spanish mackerel is a pelagic species found throughout the GOM in estuaries and on the continental shelf to depths of 100 m (Figure 23, NOAA 1985).

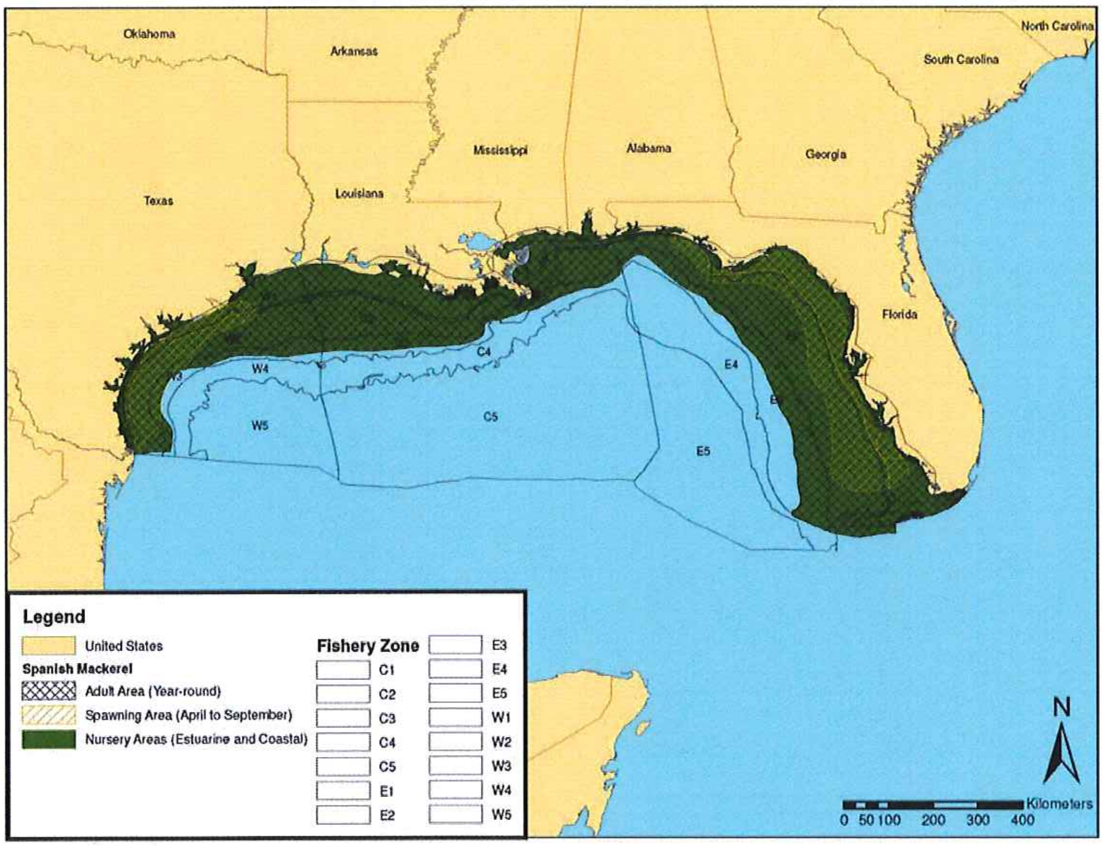


Figure 23. Distribution of Spanish mackerel in the GOM. Source: NOAA (1985).

The Spanish mackerel ranks 6th in the GOM recreational fishery with over 2.7 million pounds (1.8 million fish) landed annually. Over 96% of landings are from Alabama (9%) and western Florida (87%) waters. Only 6,000 fish are taken each year in Texas waters. The commercial fishery for Spanish mackerel is relatively small with annual landings worth $732,000 (1.3 million pounds). Commercial landings occur almost entirely off Alabama (58) and western Florida (41).

Like king mackerel, Spanish mackerel move from south Florida into the northeast GOM in spring and return to Florida in the fall (NOAA 1985). In the GOM Spanish mackerel spawn offshore over a protracted season from April to September (Godcharles and Murphy 1986). Spawning is believed to occur at night and more than once a season.

King and Spanish mackerel are discussed together because the literature search could not compile a complete suite of life history parameter values for either species. Daily natural mortality rates and stage duration rates for larvae have been reported for both species (see Tables 8 and 9). Natural mortality rates for eggs have been reported for neither (see Table 6). Egg duration times have been reported for Spanish mackerel but not for king mackerel (see Table 7).

Black Drum (*Pogonias cromis*)
Rank 8: (Recreational Fishery)

The black drum is distributed throughout coastal and estuarine waters of the GOM from Florida to the Yucatan but is most abundant in Louisiana, Texas, and northern Mexico (Figure 24, NOAA 1985). Annual commercial landings average 5.0 million pounds yielding nearly \$3.6 million. Landings are limited primarily to Louisiana (49%) and Texas (50%). In terms of dollar value, the black drum ranks 16th in the Gulf commercial fishery. Commercial fisheries operate largely in estuaries and bays but in Louisiana fishing may occur in coastal waters within the 20 m isobath (NOAA 1985). Recreational fisheries (FL, AL, MS, LA) take approximately 2.6 million pounds (581,000 fish) of black drum annually with another 79,000 taken in Texas waters. Black drum rank 8th in recreational landings by weight in the GOM. Over 78% of the recreational take is from Louisiana waters.

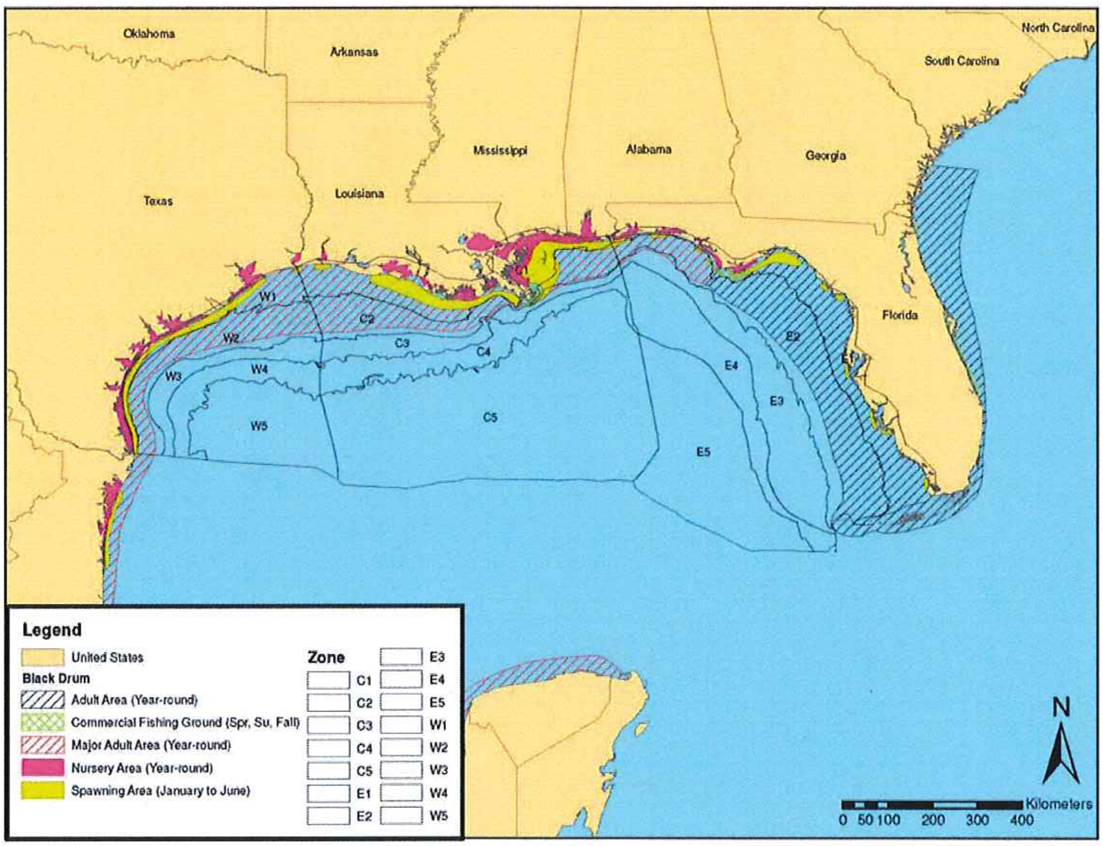


Figure 24. Distribution of black drum in the GOM. Source: NOAA (1985).

Adult black drum are primarily an estuarine species (Hoese and Moore 1998) but have been taken out to a depth of 27 m and occasionally to 37 m (Ross et al. 1983, Cody et al. 1985). They spawn in or near coastal passes and in open bays and estuaries (Sutter et al. 1986) well within the 20-m isobath.

Based upon future development projections, no CWIS facilities are planned for waters shallower than 200 m (i.e. Zones E1-E3, C1-C3, W1-W3). Because the reproductive activities of black drum are associated with shallow nearshore estuarine waters of the Gulf inside the 20 m isobath, entrainment by offshore CWIS is not an issue for this species.